THE DETERMINANTS AND RATE OF TECHNOLOGICAL CHANGE: THE CASE STUDY OF THE DEVELOPMENT AND THE DIFFUSION OF THE TRACTOR

By

ROBERT KYLE ALLDREDGE

A thesis submitted in partial fulfullment of
the requirements for the degree of

MASTER OF ARTS

WASHINGTON STATE UNIVERSITY
Department of Economics
1978

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of ROBERT KYLE ALLDREDGE find it satisfactory and recommend that it be accepted.

Stanton Smith
Chairman

John T. Donnelly

Warren S. Gramm

ACKNOWLEDGMENTS

I would like to express my thanks to D. Stanton Smith, Warren S. Gramm, and John T. Donnelly for serving on my Thesis Committee and for their helpful comments and suggestions. I would further like to thank Greg Danford for help on numerous occasions. Finally, I would like to thank my wife, Kathi Alldredge, for typing several preliminary drafts and the final copy of the thesis and most of all for her understanding.

THE DETERMINANTS AND RATE OF TECHNOLOGICAL CHANGE:
THE CASE STUDY OF THE DEVELOPMENT AND
THE DIFFUSION OF THE TRACTOR

ABSTRACT

by Robert Kyle Alldredge, M.A.
Washington State University, 1978

Chairman: D. Stanton Smith

The purpose of this paper is to study the process of technological change. An important part of the study of technological change is the examination of the determinants and rate of technological change. This paper focuses on the development and the diffusion of the tractor from its invention in 1892 to its nearly complete adoption in 1950.

The diffusion of the tractor occurred over a long period of time. The purpose of this study is to explain the reasons for the lengthy diffusion process. It is hypothesized that the cause of the slow diffusion rate of the tractor was the lack of economic incentives. It is argued that the adoption of the tractor occurred when that adoption resulted in an increase in profits to the farmer.

The primary analytical section of this paper attempts to measure the costs of operation of both the tractor and the horse. It was the technique of farming with the horse that competed most strongly with the tractor. The results of the analysis indicated that there were several supply and demand variables most responsible for changing costs of both tractor and horse costs. As these

variables changed over a period of years, the cost differential between farming with a tractor changed in relationship with farming with a horse. It was found that the costs of operating a team of horses was competitive with the costs of operating a tractor for a significant part of the time period under study. It was only the later years of the study that the horse ceased to be competitive on the average farm.

The relatively slow diffusion rate of the tractor occurred because the horse was a viable technique of farming. It was the lack of economic incentives that was the result of the lengthy diffusion rate of the tractor.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

The study of technological change is a subject of major importance that is overlooked by many economists. An important part of the study of technological change is the examination of the determinants and rate of technological change. This paper focuses on the development and the diffusion of the tractor.

The diffusion of the tractor occurred over a long period of time. The tractor was not completely adopted by farmers for over half a century. The purpose of the study is to explain this lengthy diffusion process. There are two possible explanations of the long diffusion process. The first is that the farmer delayed adoption of the tractor because of the lack of economic incentives. The second is that the farmer delayed adoption for reasons unrelated to economic incentives. It is hypothesized that the cause of the slow diffusion rate of the tractor was the lack of economic incentives to the farmer. There were other techniques of providing power on the farm that were competitive with the tractor. It is argued that the adoption of the tractor occurred when that adoption resulted in an increase in profits to the farmer. This study attempts to substantiate that hypothesis.

The first chapter of the paper discusses the meaning of the concepts of technology, techniques, and technological

change. Included within this first part is an examination of the nature of technology. The second chapter summarizes the literature on the diffusion of new technologies. It begins with some basic concepts of technological change written in the field of Anthropology. This is followed with a brief review of the literature from Sociology and a more extensive review from Economics. The major analysis and findings for the paper are discussed in the third chapter. It specifically deals with the development and the diffusion of the tractor. The fourth chapter discusses the implications of the process of technological change. It attemps to relate the nature of technological change with the diffusion of the tractor.

The process of technological change is more relevant in the twentieth century than any other period in history. Many observers call modern western civilization a "technological society." This paper hopes to help illustrate the determinants of this process of technological change and draw attention to some of the important factors relevant in the study of it.

CHAPTER 1

TECHNOLOGY

The Definitions of Technology

A technological society is becoming increasingly a part of everyday life. Technology is so interwoven into today's society, it seems hard to imagine a society without technological advances. Even the most underdeveloped countries rely on technology imported from the West. Technology is a reality of life, one which must be considered in any future society. Individuals who devise a society completely void of all technology are only devising an illusion.

Technology is a word which connotes many ideas. It has usually signified progress to the majority of individuals. It also brings to mind the evolution of machines, the automated assembly plant, supersonic aircraft, spaceships, new automobiles, plastics and, most of all, the computer. These symbolize technology to most citizens. Technology is pictured as a way to improve our society. But technology represents different ideas to a new and increasing type of person. This is the person wishing to live in harmony with nature. They wish no machines and no technology to interfere with the natural environment. Technology is despised as destroying the environment. Technology is again pictured as the evolution of the machine and is attacked

for causing air and water pollution, dehumanizing the worker, congesting the cities, and defoliating the countryside.

To help understand the conflict about technology, it is essential to come to an agreement to the definition of technology. Exactly what is meant by this concept? Within the literature on technology there seems to be scores of definitions. Each writer develops a new definition to suit himself. Talcott Parsons states that ". . . technology is the socially organized capacity for actively controlling and altering objects of the physical environment in the interest of some human want or need."[1] Emmanuel Mesthene defines technology ". . . as the organization of knowledge for the achievement of practical purposes."[2] Daniel Bell noted that technology is ". . . not simply a 'machine,' but a systematic, disciplined approach to objectives, using a calculus of precision and measurement and a concept of system . . . ."[3] Victor Ferkiss argues that technology should be defined ". . . as a self-conscious organized means of affecting the physical or social environment, capable of being objectified and transmitted to others, and effective largely independently of the subjective dispositions or personal talents of those involved."[4] Jacques Ellul differs from the others in the fact that instead of defining technology he defines techniques. He states that ". . . technique is the totality of methods rationally arrived at and having absolute efficiency (for a given state of development) in every field of human activity."[5]

Though each definition is different for each writer, there are great similarities between the meanings of techology or technique. Generally, technology or technique is a rational, organized, and systematic approach or method which is used to control the environment for the purpose of achieving human wants, needs, or objectives. This is what is meant by the term technique, while technology refers more to a general category of techniques as a whole. This meaning of technology is broad and includes many types of activities.

Generally, many people have thought of technology as consisting entirely of production or industrial techniques. It is given a broader meaning here, but production techniques are a subset of techniques. Technological change needs to be defined. It can be considered as simply a change in the current technologies that are presently in use. In the case of production techniques, a technological change refers to a change in the production function. This illustrates that the method of production has undergone a change. A technological change occurs when there is a change in technique.

The Technological Process

Technique must be thought of as a process. It is a process that rationally and objectively obtains human wants or needs. Consider a technique in the manufacturing of automobiles. This particular technique enables automobiles to be built at a low cost to the producer. The individual receives an automobile which is similar to others, but for less money.

Too many times, this is all that is considered before the technique is adopted. Economic criteria is the only consideration. The determining factor of technological change is the cost to the producer. There are other criteria that should be examined. Every technique should be examined in its entirety. Both the technique itself and the result or product of that technique are important in determining the implications of the technique. This particular technique is a rational, objective, systematic method of producing a low cost automobile. The design of the technique may include the use of an assembly line or the use of individual craftsmen. It may include high or low wage rates to its workers. It may provide the workers with safe or unsafe working conditions. Not only is the technique itself important, but also the result or product of the technique. The automobile may or may not get as good gas mileage as automobiles produced by other techniques. It may not have as many safety features or as much horsepower. It may only continue to operate for one half the time as the other automobiles. The nature of the technique may either alienate the worker or help the worker to develop his individuality.

It is also necessary to examine the nature of the product of the technique. The automobile has had numerous effects upon the style of life in the post-industrial society. Workers live further from their employment. The air in the cities becomes polluted. Billions of dollars have been spent on highways. These are only a few implications of this technique.

With all of these implications, does it make sense to adopt a technique only when it is evaluated by economic criteria? Marshall McLuhan has emphasized the examination of technology to a fuller extent in his studies of the media. New electronic technology has produced and developed the television and radio. The examinations of the impact of radio and television is necessary to determine the effect of this technology on society. What McLuhan concludes is that the content of the television programs or the radio messages are only a partial inquiry into the implications of these electronic inventions. A much larger impact is made by the use of the television or radio by itself, irregardless of the content. McLuhan states that "Indeed, it is only too typical that the 'content' of any medium blinds us to the character of the medium."[6] This illustrates that all aspects of techniques and their products must be given consideration before attempting to measure the benefits and costs of a technological change. Cursory examination of any of the aspects of techniques gives only partial knowledge of the technique. To gain a full understanding of the impact of technology and technological change, individual techniques and their results or products must be examined to the fullest extent possible.

It should be clear that technology, as a whole, has little meaning without the examination of individual techniques. Techniques are a means to an end. The means may or may not be considered beneficial. Both the means (techniques) and the ends

(objectives) must be examined in relationship to the rest of the social system. Those who consider technology to be synonymous with progress are as much in error as those who consider technology to be synonymous with destruction. Indeed there are many techniques which are consistent with most people's conception of progress. These may include medical techniques, such as penicillan or artificial bone structures. On the other side, there are many techniques which are leading to environmental and social destruction of our society. Techniques used in the agriculture sector, such as the use of DDT, other pesticides and fertilizers, have had harmful impacts upon the biological lifecycle. Techniques in the production of energy have had similar effects. These include the burning of gasoline in the automobile, the use of nuclear reactors for the production of electricity and the burning of coal for the production of heat and electricity. Products of techniques have also had destructive effects upon the society. The use of cigarettes, alcohol and the automobile have resulted literally in millions of deaths to consumers of these products. All of the implications can never be understood. It would be extremely difficult to even understand the most significant implications from a single technique. The point is that the study of individual techniques, such as the farming techniques used in this paper, should be interdisciplinary in scope.

Types of Techniques

There are basically three types of techniques which operate within the society. These are physical techniques, non-physical techniques and techniques which are a combination of the first two. The physical techniques are those methods or approaches which control the physical environment, such as the technique of telling time by the use of the clock. Non-physical techniques could include a technique entirely involving humans. The technique of management in the use of the division of labor falls within this category. The final type is a combination of physical and non-physical elements. An example is the technique for the production of automobiles, which uses both machinery and human labor to operate it.

Physical techniques are an important element in our industrial society. These techniques have had an immense impact upon our society for hundreds of years. These techniques are most frequently associated with machines. While most machines cannot be used without human control, the specific goals of the technique can be carried out by the machine once the machine is set in motion. The clock, printing press, computer, camera and gasoline engines are only a few machines which function as physical techniques. The clock serves as an excellent example to illustrate the role of these particular techniques. The clock is a method to efficiently keep time. It is an organized and systematic method to achieve an object, which is to keep accurate time. Once the clock is set in

motion, it is able, on its own accord, to perform its objective. It does not rely on further human intervention. This makes it a physical technique. To fully understand the clock or any machine, it is important to know the nature of the machine. Lewis Mumford states that a machine should be defined ", . . . as a combination of resistant parts, each specialized in function, operating under human control, to utilize energy and to perform work, . . ."[7] The important part of the definition is that a machine is made of specialized parts, each of which has a specialized function. The clock is made of hundreds of specialized parts, each one carrying out a separate function. To understand how the whole clock works, the parts can each be examined and systematically analyzed.

The machine has undoubtedly had major impacts upon the society. These impacts have been both favorable and unfavorable. But as Lewis Mumford said, the machine operates under human control. As was mentioned earlier, each machine which is used as a technique must be examined in its entirety. This means that the technique and the result of the technique need to be examined. It is still up to man to determine the use of the machine.

The second category of techniques can be called non-physical techniques. These are techniques in which non-physical components, primarily human, are involved. Bureaucracies, advertising methods and educational methods are illustrative of this type of technique. Again, these are organized, systematic

approaches to objectives. Advertising techniques are an example that are illustrative of this type of technique. Advertising is a technique which persuades the public to buy a product or an idea. The advertiser may be selling the idea that children should be vaccinated against polio or that smoking is dangerous to one's health. He may be trying to persuade the public to buy a new model of automobile. The advertising technique, in any of these cases, may be the same, with the only difference being the ideas or products sold. The technique is not what is different. The objective of that technique is different. A technique must be examined in all of its aspects, including the objective(s) of the technique. The technique and its objectives must be seen as a single relationship to be able to evaluate it completely. The non-physical techniques are designed to control the environment as are the physical techniques. They are approaches or methods to achieve human objectives through human components.

The third type of technique is a combination of both physical and non-physical parts. A technique to assemble automobiles is illustrative of this type of technique. Both machines and human labor are used to completely assemble an automobile. To efficiently produce an automobile for General Motors it is necessary to employ both man and machine. Neither men nor machines alone would be able to completely assemble an automobile at a reasonable cost to the company. The third type of technique is perhaps the most common and important type in

the industrial society. The tractor is one example of this type of technique. It involves the machine component and the human component. As with other techniques, it is the approach or method of controlling the environment for the purpose of achieving human objectives.

Technological changes cannot be examined solely through economic criteria. While it may be true that ecomonic variables can explain most reasons for the adoption of industrial techniques in our culture, economic analysis will not identify many of the implications of that technique. A full examination of individual techniques must be interdisciplinary in scope. The following part of the paper will examine the process of adoption of new techniques in an interdisciplinary manner.

Chapter 1--Notes

1 Nathan Rosenberg, Technology and American Economic Growth (New York: Harper and Row Publishers, 1972), p. 18.

2 Emmanual G. Mesthene, Technological Change: Its Impact on Man and Society (New York: New American Library, Inc., 1970; Mentor Books, 1970), p. 25.

3 Victor C. Ferkiss, Technological Man: The Myth and the Reality, with a forward by Elting E. Morrison (New York: New American Library, 1970; Mentor Books, 1970), p. 37.

4 Ibid., pp. 37-38.

5 Jacques Ellul, The Technological Society, trans. by John Wilkenson, with an introduction by Robert K. Merton (New York: Random House, 1964; Vintage Books, 1964), p. xxv.

6 Marshall McLuhan, Understanding Media: The Extensions of Man (New York: New American Library, Inc., 1964; Signet Book, 1964), p. 24.

7 Lewis Mumford, The Myth of the Machine, vol. 1: Technique and Human Development (New York: Harcourt Brace Jonanovich, Inc., 1966; A Harvest Book, 1967), p. 191.

CHAPTER 2

THE DIFFUSION PROCESS

The Diffusion Process in Anthropology

The study of the diffusion of the tractor is the study of the adoption of a new technique by the farmer. An important part of the diffusion process is the rate of adoption and the reasons or determinants of the adoption of the new technique. It must be made clear, from the start of this paper, that only one culture is being examined. That is the culture of the American farmer in the first part of the twentieth century. The reasons for the adoption of the tractor by this group may or may not be similar to the reasons of the adoption of other agricultural machinery in other cultures. An anthropological description into the diffusion process will give insight into the adoption of techniques by various cultures.

Different cultures are not alike and the determinants of the adoption of new techniques will not be the same. Ralph Linton stated that "New traits are accepted primarily on the basis of two qualities, utility and compatibility: in other words, on the basis of what they appear to be good for and how easily they can be fitted into the existing culture configuration."[1] Each culture already has adequate technique for meeting most of the needs of their society. New techniques may be adopted if they are an improvement over the old techniques. An improvement does not necessarily mean that the technique is

evaluated in economic terms. In many cultures, non-economic considerations are more important:

> When a new trait presents itself its acceptance depends not so much on whether it is better to make its acceptance worth the trouble. This in turn must depend upon the judgment of the group, their degree of conservatism, and how much change in existing habits the new appliance will entail. Even in the simplest form of diffusion, that of mechanical appliances, superiority cannot be judged simply in terms of increased output . . . In many parts of Oceania the natives have been receptive to European plane irons, which they could haft and use like ther original stone adzes, but have refused to accept the vastly more efficient axe simply because they did not like to work with it.[2]

The other quality that Linton found important was the compatibility of the new technique to the culture. Some techniques are simply not compatible within certain cultures:

> If the new trait is of such a sort that its acceptance will conflict directly with important traits already present in the culture, it is almost certain to be rejected. One cannot conceive of techniques of mass production being accepted by a culture which had a pattern of uniqueness. There actually are societies which believe that no two objects should ever be the same and never make two things exactly alike.[3]

In the study of the diffusion process, both the utility and the compatibility of new techniques are important in understanding the rate and diffusion of new techniques.

There is another point that comes from the anthropology literature. H. G. Barnett argues that it is necessary not only to find a correlation between two types of behavior, but it is also necessary to find the corresponding rationale for that relationship. He states "As we know, 'figures can prove anything,' and the reason, as far as human behavior is concerned, is that they treat with consequence and not with the

mental linkages between them. While this is probably more important to consider when examining different cultures, it is also important when examining one's own culture. It is easy to find correlations between different types of behavior. It is more difficult to find or understand the linkages between that relationship. The economist may find a relationship between two types of behavior that perfectly fits a complex theoretical model. That may be all that is necessary when the only objective is to predict future events. But if the objective is to explain exactly what has happened, then the rationale of the bahavior must be understood. The determinants and the rate of the diffusion of the tractor must be understood from the viewpoint of the farmer, not the economist.

It would be helpful to get a background of the American culture as it relates to this study. The American culture is undoubtedly very much concerned with economic considerations, any free market system must be. This is expecially true for the farmer. He owns his own farm and must be able to make enough profit to avoid losing it. Any analysis of the American culture will show that utility is associated with economic considerations and that most technological changes that have economic advantages are compatible with our culture. Changes in techniques that are more economically efficient are a part of our culture and people praise and accept them. The American culture is one of change. Linton makes a comment on it:

> The average member of a society takes his culture very much for granted, and unless a new element is of obvious advantage he will usually be chary in accepting it. Anything which departs too far from the established patterns will be viewed with suspicion and is more likely to bring its inventor riducule than prestige. We must remember that the high-pressured salesman with his techniques for developing a consciousness of new needs in a society is as much a special product of our culture as the electric razors and cigar-lighters which he attempts to sell.[5]

Changes are a part of the American culture. There are high-pressured salesmen who do promote change. Salesmen promote changes in dress and perfume to make one more appealing to the opposite sex. They promote changes in industrial techniques, which are more economically efficient. While other cultures stay the same over thousands of years, the American culture is always in the process of change. But Linton is absolutely correct in stating that people are wary of new techniques which do depart from the established patterns of behavior even in the American culture. A new technique to build glass houses would be ridiculed because of the American desire for provacy. This is not compatible with our established culture. New techniques which are less economically efficient and are more aesthetically pleasing or less alienating to the worker are not accepted by businessmen because they lack utility. Techniques are adopted by businessmen because they are economically efficient. This is thought a good reason for accepting them in our culture. Economic considerations play a large role

in the measurement of utility. While our culture permits rapid changes, they must fit the established patterns of behavior. These considerations, which are primarily part of the anthropology literature, will be related to the diffusion of the tractor.

The Diffusion Literature in Sociology

The largest literature on the subject of the diffusion process is probably in sociology. Many studies by rural sociologists examine the adoption of new techniques in rural America. Most of the sociologists examined the diffusion process through stages. Beal and Bohlen state that this process can be broken down to five stages.[6] These are the stages of awareness, interest, evaluation, trial, and adoption.[7] In the awareness stage, the individual becomes aware of the new technique. In the case of a new technique in farming, this stage refers to the time the farmer comes into contact with the idea. This contact could come from neighbors, radio, television, salesmen or elsewhere. The next stage in the process of diffusion is the interest stage. This refers to the individual becoming interested in the new technique and seeking additional information about it. The third stage is the evaluation stage. At this time, the individual has obtained information about the new technique and is attempting to measure the costs and benefits from the adoption of the technique. If the individual decides that the new technique may be beneficial, he may try it out on a small scale. This is the trial stage.

In a case where the technique is divisible, such as hybrid corn, the farmer will probably only plant a few acres in the new seed to better evaluate it. The last stage is that of the adoption of the technique. If the individual finds the new technique to be satisfactory, he will accept it for further use. Sociologists argue that the individual goes through these five stages before the final diffusion of the technique. The diffusion process could be delayed at any one of these stages.

The most important of these stages is the evaluation stage. In most cases, the awareness stage is completed rather quickly, especially if there are salespeople and advertisements attempting to sell the new process. One delay that could come in this stage is with techniques which are kept secret from other competitors in the industry. This leaves the evaluation stage in a critical position. This is especially true for techniques that are not divisible. The tractor falls into this category . The major deteminant of the adoption of the new technique is its efficiency compared to the old technique. Wilkening states: "The greater the efficiency of the new technology in producing returns in the form of economic or consumption goods or satisfactions, the greater the likelihood of its acceptance."[8] While sociologists agree that the efficiency of the new technique is of great importance in determining the rate of adoption, other variables are also stressed. These include community identification, family and individual variations and informal leadership structures. Wilkening argues that community or group identification is important. He

states "As has been pointed out, people behave not as isolated beings but as members of groups having certain standards, values and norms."[9] The rate of diffusion of new techniques is partially dependent upon the relationship between the individual and the group. Groups can either accelerate change or delay change. In addition to the community groups, variations in families and individuals can cause differences in the rate of adoption of new techniques. Beal and Bohlen state:

> Decision making is influenced by the aspirations and capabilities of farm families. Individual member and family aspirations are reflected in their goals, values and means of achievement. Their capabilities include general farm knowledge and managerial skills of the operator and his family. These are related to such things as age, formal education, socioeconomic status and social contacts.[10]

The goals set by the individual, the family or possibly firms may run contrary to the adoption of new techniques. Socio-economic variables may lead some individuals to adopt techniques and discourage others. Some individuals have the skill to easily manage and operate new processes which others do not.

Individuals can be separated into several categories by their rate of adoption of techniques. With some modifications, it is also applicable to firms. Each of these groups have certain characteristics. Beal and Bohlen list five categories. These are the innovators, early adopters, early majority, majority, and non-adapters.[11] Innovators are the first people to adopt a new idea. These people are generally active in the community, belong to formal organizations, receive information from colleges or other specialists, read more papers and

magazines, are younger and are of a higher socioeconomic status. From this first group to the last group, the individuals become less educated, older, participate less in community activities, read fewer papers and magazines, and are of a lower socioeconomic status.[12]

Informal leadership structure can also effect the rate of change. Many individuals in a community look to the leaders for information and guidance. These leaders can be influential in the time it takes new ideas or techniques to diffuse. If the leaders are quick to adopt new techniques, others who can be considered followers will likewise adopt that technique. In a similar manner, change agents may play a role in the diffusion of a new technique. The change agent ". . . is a professional person who attempts to influence adoption decisions in a direction that he feels is desirable."[13] These change agents are usually salepeople or dealers persuading the individual or firm to adopt a new technique.

The individual and the "firm" are integral parts of society and function in accordance with the norms of the society. Depending upon the situation, this functioning may either increase or decrease the rate of the adoption of new techniques.

These non-economic variables are possible influences upon the rate of adoption. While they may not be as significant as economic variables in the determinations of production

techniques, there is a need to examine them. The sociological variables, in some cases, may be the prime determinants of the rate of technical change.

The Diffusion Process in Economics

The Theory of the Diffusion Process

Economists have argued that the diffusion process can best be analyzed with the use of economic variables. It would be expected that economic considerations should play an important role in the determinants and rate of technological changes, especially within the production process of industries. It is technological changes in the production process that economists have examined most frequently. These changes have had a major impact upon the entire economic system. (It is to be remembered that the diffusion processes are relevant to western industrial countries and may be entirely different in other parts of the world. The studies analyzed in this paper come primarily from the United States and Great Britain.)

The economic literature of the diffusion of new production techniques usually asserts that it is the profit motive of firms and individuals that determines the rate of diffusion. New techniques are adopted to enable the firm or individual to make a normal profit. Some studies have noted that other non-economic considerations are also important. This brings us directly back to the ideas developed in the anthropology literature. There, it was stressed that the factors regarding

the rate of adoption of new techniques depended upon both utility and the compatibility of the technique with its culture. The economists have used the same type of analysis but have considered utility to mean profitability, while at the same time suggesting that the compatibility of the new technique within the culture is of little importance. The economist is generally concerned with the adoption of new techniques in the production process of industries. This fact suggests that the utility of a new production technique is very closely correlated with profitability in the eyes of the businessman. Other types of utility or disutility may also be associated with the technique and will likewise be examined, as will the compatibility of the technique within the culture.

The profitability of the new technique is the primary factor examined in the economic literature on the diffusion process. It then becomes the task of the economist to determine the point in time that the new technique becomes profitable and to determine the rate of adoption once it has reached this point. One of the most important problems is the determination of whether a new technique is profitable. This must include many factors. Some of these factors are the following: (1) size of the investment for the new technique, (2) size of the investment for complementary factors of production, (3) productivity advances of the new technique, (4) size of the market, (5) cost of financing the investment, (6) uncertainty, (7) depreciation of new machinery and old machinery, (8) profitability of

existing technology, and (9) present and future prices.[14] There are many considerations which need to be taken into account to determine the profitability of a new technique. This preceeding list includes the most important factors. Examination of the profitability of a new technique can be illustrated by use of graphs. If it is assumed that the firm is in a perfectly competitive industry, then Figure 1 illustrates two firms using different techniques. These different techniques result in the average cost for firm 1 to be higher than the average cost for firm 2. While firm 1 is making normal profits, firm 2 is making substantial economic profit. The technique used in firm 2 is undoubtedly more profitable than the technique used in firm 1. In this case, it would prove profitable for firms to use the new technique when building a new plant or replacing their old plants. In the long run, all firms would adopt the new technology. But this is a very simplistic view of the adoption of a new technique. It is easy to state that the new techniques will be adopted in the long run, but more difficult to determine at what point in time they will be adopted.

The point in time when a new process will be adopted depends on the nature of competition and on the nature of the costs of the old techniques and of the new techniques. The importance of these distinctions are illustrated in Figure 2. Three techniques of production are depicted. Technique A is the existing technique, with plants embodying the technology

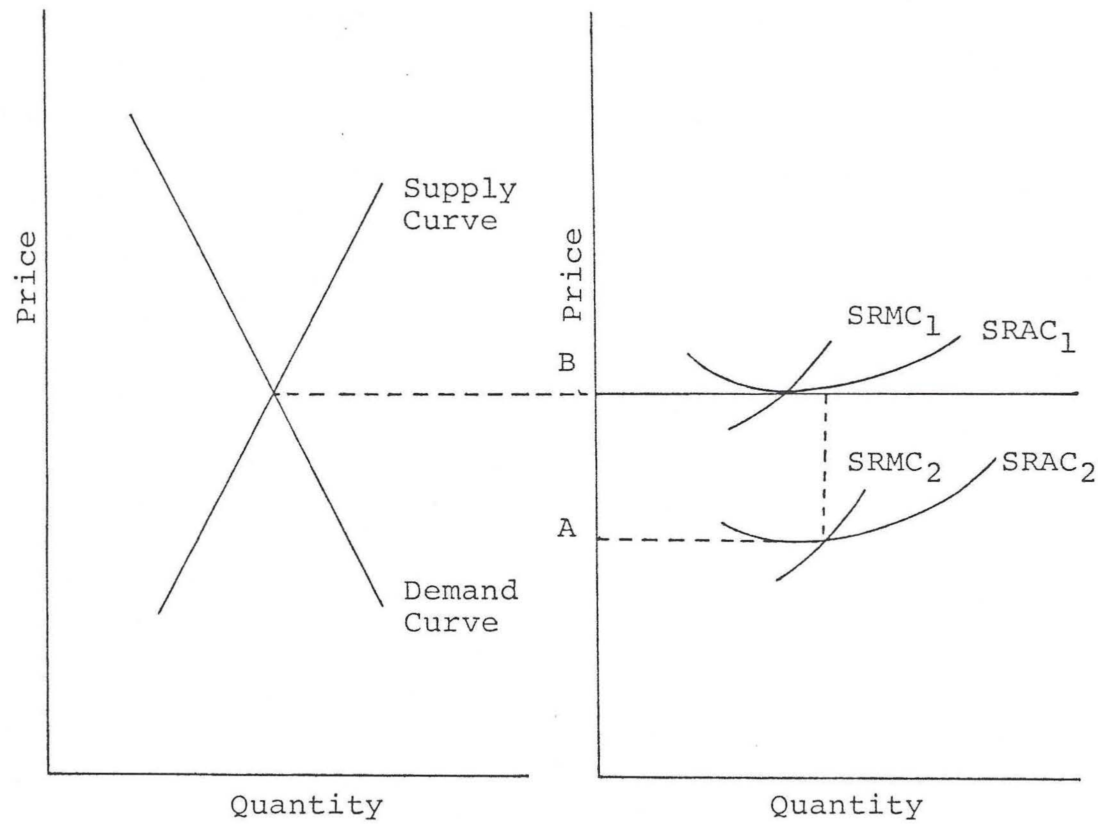

Fig. 1.--The relationship between two competing techniques that have different short-run average costs showing the economic profit derived from the more efficient technique.

giving rise to the short run average fixed cost (SRAFC) and short run average variable cost (SRAVC). Two alternative new techniques are shown, B and C; B with a total average cost just above the SRAVC of A and C with a total cost below the SRAVC of A.

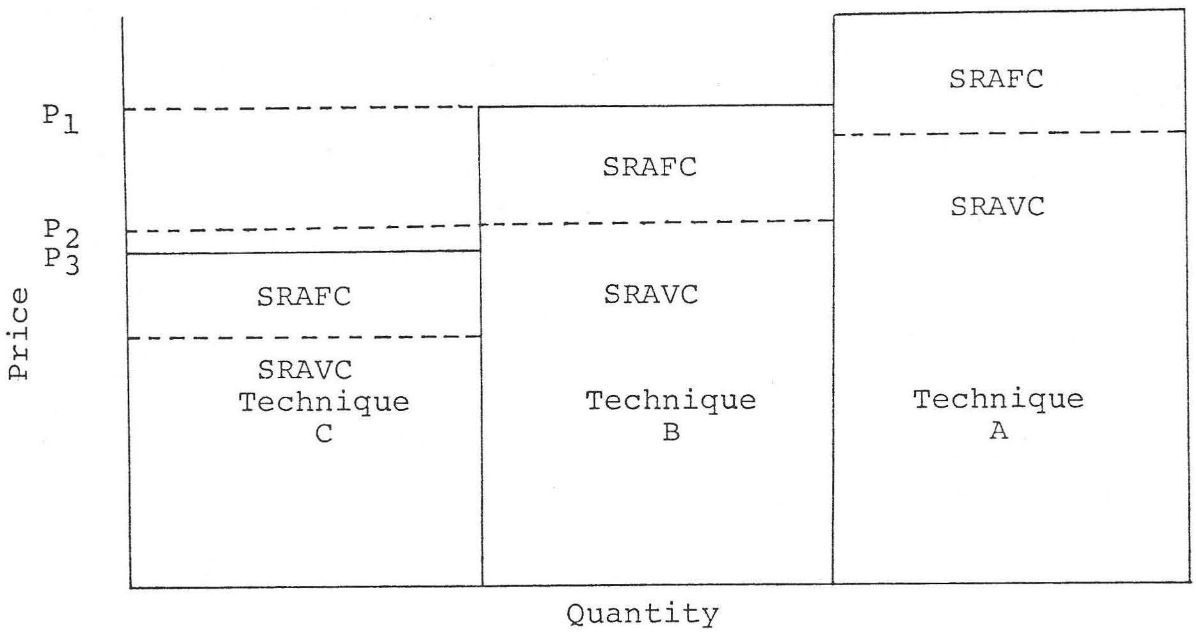

Fig. 2.--The relationship between the short-run average variable costs and the short-run average fixed costs for three competing techniques.

Assume first that the industry is composed of one or a few firms who will maintain the price P_1 (or some higher price). It is also assumed that entry into this industry is not possible. If technique B is the new technique, the firms will continue to operate the old plants until replacement is required due to the deterioration of capital equipment, because the full cost of B (which is all "variable" for planning purposes) exceeds the variable cost of A. Thus, the new technique may not be used for an indeterminate number of years, depending on how long-lived the old capital is. If

C is the new technique, then the firms will adopt the technique as soon as the new plants can be built because the full cost of C is less than the SRAVC of A.

Now assume the new process is discovered in a competitive industry where entry is possible. If the new technique is B, new firms will be established immediately because an economic profit is available at the price (P_1), which covers the full cost of technique A. The price will be driven to P_2, covering the full cost of B, but the old plants embodying technique A will continue to operate because the price covers the SRAVC. As the old plant(s) wear out, new plants using technique B will replace them. Thus, for technique B, the new technique will be introduced immediately. The full adoption of the new process will occur at the same point in time as would have occured under the oligopoly model.

If the new process were C, then new entry will drive the price to P_3, the old plants will be closed because SRAVC for technique A is not covered, and the new process will be introduced as rapidly as the new plants can be built. In this case, adoption will occur as quickly as under oligopoly.

An important question in the diffusion literature is whether the industry is in some sort of equilibrium or disequilibrium until the new technique is fully adopted. To understand the issue, Figure 2 is re-examined. Technique A is the technique presently in use. If technique C is the new technique, then the only equilibrium position is the full adoption of technique C throughout the industry. This is because the total

costs of technique C are lower than the variable costs of technique A. If technique B is the new technique, the answer is not as simple. The total costs of technique B are lower than the total costs of technique A, but not lower than the variable costs of technique A. Technique A will continue to be operated until the time the capital wears out; only then will technique B replace it. If technique A were composed entirely of variable costs, then the firms in the industry would immediately shift to technique B. Techniques embodying high fixed costs delay adoption of new technologies. Even though both technique A and technique B may be in operation at the same time, it is an equilibrium situation. There are no incentives to change. A disequilibrium situation would arise in the event that there were economic incentives to adopt a new technique and it was not adopted. But because an industry is composed of competing technology, even though one is more efficient than the other, does not necessarily indicate a disequilibrium.

The preceeding few pages outlined the process of adoption of new technology in both competitive and oligopoly industries. The diffusion of the tractor occurred in as competitive an industry as there is in the United States. The large majority of farmers adopted the tractor to replace other methods of providing power. The farmer examined the costs of tractor operation in comparison with the costs of other techniques on the basis of a constant supply of land to be harvested. Because the adoption of the tractor was generally a replacement decision,

the rate of adoption depended partially on the nature of the fixed costs of older techniques. A technique embodying high fixed costs (steam traction engines) would delay adoption of a more efficient method of farming for a greater length of time than would a technique embodying low fixed costs (horses and mules). In both cases, full adoption would occur in the long run. In the short run, because of the nature of costs, an equilibrium may have occurred with the use of more than one technique of farming.

A cursory examination of the problems associated with the determination of the point of profitability in both a competitive industry and an imperfectly competitive industry has been discussed. The next question the economist must answer is: What factors caused a new technique to reach the point of profitability? It can reach the point of profitability because the demand conditions have changed, supply conditions have changed or both demand and supply conditions have changed. A good example of supply change would be a change in factor prices. Labor costs may increase in comparison with capital costs. This would result in an increased demand for labor saving techniques. As the labor costs increase, compared to the capital costs, there will be a shift to more labor saving techniques because the firm will substitute capital using techniques for labor using techniques. A change in demand conditions can also lead to new techniques. One important difference in techniques is economies of scale associated with those

techniques. A new technique may have significant economies of scale, but because of a firm or individual inability to increase sales that new technique cannot be used. Uncertainty is another factor that can cause delay in the adoption of new technology. Without perfect knowledge, the firm or individual may not be aware of the advantages of the new technique. When a new innovation is introduced, it is likely that there is much uncertainty associated with the adoption of that technique. This could result in a type of bandwagon effect. The rate of adoption may increase with the number of the firms which are using that technique. The supply of skilled labor and materials may also be a factor determining the demand for a new technique. Even though it is realized that the new technique is superior to the old technique, it may be that the new technique employs skilled labor or materials of a type that are not available. The new technique cannot be adopted until the supply of labor or materials is expanded. This may occur because of changes in income, tastes or prices. Other non-economic considerations that influence demand are discussed later. The main economic determinants of demand are factor prices (and/or the availability of the factors), economies of scale, uncertainty, and increases in the firm's demand for the product.

Another factor which can influence the profitability of a new technique is an improvement in the new technique. Many times, a new invention is developed that appears to be

a major breakthrough in some production process. But that invention may need many improvements before it can efficiently replace the old technique. How important these "secondary inventions" are can be easily overlooked. The original invention is very important, but the many minor improvements that follow may increase the productivity and profitability of that invention a great deal. Such advances also occur in the old technologies. Even though the new technique has become more profitable than the old technique presently in use, there may be technological advances to the old technique that could delay the adoption of the new technique.

There may be a lack of skilled labor to construct the machines. Many of the new techniques require very complex machinery and must be manufactured with precise accuracy. This problem was common during the early industrial expansionary period. It has been mentioned many times that geniuses, such as Leonardo da Vinci, designed inventions that would have been revolutionary if only the skilled labor and materials required for construction had been available. A similar situation could also arise because of the marketing and repair problems. Firms or individuals may be hesitant to adopt the new techniques until marketing outlets and repair shops are widely diffused to insure that problems with the new technique can be worked out. The supply of replacements parts and repair service cheapen the long run cost of the new technique. Greater efficiency in the production process of new techniques may have significant impact

upon costs of production and final selling price of the technique. Economies of scale are also important in the production of the new technique. The production of the necessary machines and other equipment may have significant economies associated with them. This is especially true when only a few are being built. Unit costs can substantially decrease when output reaches a higher level.

An examination of several important case studies will clarify the process of the diffusion of new techniques. An understanding of these will help to identify the determinants of the rate of diffusion.

Hybrid Corn

In the early 1930's, the commercial use of hybrid corn was beginning. This corn, which is produced from crosses between plants, produces a higher yielding corn. The work done by Zvi Griliches on the diffusion of this new technique is a classic statement on the subject.[15] Griliches observes that the diffusion of hybrid corn in various states follows an S-shaped growth curve. This diffusion pattern, which Griliches finds for hybrid corn, has repeated itself in many other technological changes. Hybrid corn is not a single innovation for all states. Each locality must develop a hybrid corn to suit their area. There are costs involved in the development of each strain of corn in each region. Because the costs of developing hybrid corn is relatively constant in each locality, it would be expected that the adoption of this new technology would begin in the regions where the prospects of

profits for the seed producers are the highest.[16] Hybrid corn was adopted most rapidly in the areas that were the highest in corn production. Griliches states that ". . . innovators were influenced by considerations of profit, entering those areas first where expected profits from innovation were the highest."[17]

The rate of acceptance of hybrid corn by the farmers is hypothesized by Griliches to depend primarily upon the magnitude of the profit to be realized by using the new seed. This hypothesis is based upon two considerations. The first of these is that the ". . . larger the stimulus the faster the reaction to it."[18] The second is the fact of uncertainty. Until the farmers were convinced that the new seed was superior, they would not adopt the new corn.[19] If the magnitude of the profits are large, then uncertainty will be decreased because it is easier to see differences between the old and new corn seed. Griliches found that skepticism and lack of knowledge about hybrid corn slowed down the acceptance rate. He states that very few farmers plant 100% of their land in the new corn seed until they experimented with it.[20] Griliches found that profitability of a shift to hybrid corn as measured by increased yields per acre and average number of acres per farm was highly correlated with the acceptance of that seed.[21] Farms that stood to make the largest profits from a shift were the first to accept hybrid corn.

Griliches suggests that the market is in disequilibrium until a few years after the introduction of the new technique. Griliches defined equilibrium as existing when there were no longer any economic incentives to continue to adopt the new technique. Farms will adopt the new seed until it is no longer profitable to do so. Griliches found that some farms never shifted to the new seed because their land was not suitable to grow the hybrid corn.

The study of the diffusion of hybrid corn is similar to the study of the diffusion of the tractor. It was hypothesized that the profitability of the tractor determined the diffusion rate. It is expected that the larger the magnitude of profits that occurs from the adoption of the tractor, the faster the diffusion rate.

Wooden Shipbuilding

The next case of technological change is that of the persistence of wooden shipbuilding in the late 19th century.[22] During this period, a new technique for building ships from iron was replacing the traditional wooden shipbuilding technique. The new technique was not adopted throughout the industry as quickly as hybrid corn had been. Both techniques coexisted in the same market for about 30 years according to Harley.[23] Examination of the reasons for this slow diffusion of technology should throw some light upon the determinants of the rate of adoption of new techniques.

Harley argues that there are economic reasons for this slow adoption rate. It was not ignorance or uncertainty on the part of the firms that delayed the diffusion of iron shipbuilding. Harley states that:

> The continued existence of wooden shipbuilding industries long after the new industry of building metal ships was firmly established appears better explained by a hypothesis that assumes the period was characterized by a series of competitive equilibria rather than by a Shumpeterian view that diffusion was delayed by prejudice, ignorance and inertia.[24]

Harley believed an examination of the supply condition within the shipbuilding industry would indicate that wooden shipbuilding was a competitive technique. Harley analyzed the supply conditions for both the iron ships and wooden ships. The iron ships were primarily built in Britain during that period and the wooden ships were built in Canada, the United States and Britain. The main determinants of the changing price of iron ships were changes in technology, wage rates and iron prices. The determinants of the changing price of wooden ships were changes in technology, wage rates and the price of wood.

The most interesting find of Harley's paper is the fact that the adoption of iron shipbuilding did not follow a smooth S-shaped curve. In fact, the market share of the new iron ships declined several times throughout this period. Harley explains this cyclical behavior through an examination of the long run supply curves of the iron and wooden shipbuilding industries.[25] The fact that wooden ships gained market shares compared to the iron ships several times during the 30 year

adoption period provides evidence that wooden shipbuilding could compete with iron shipbuilding. Factor prices and technological changes best explain this phenomena. This was not a case where the new technique adopted was vastly superior and profitable than the old technique. Only by a relative decrease of factor prices and increased technogical change in the iron shipbuilding industry did it finally become the primary producer of ships. Harley concludes by stating, "Iron ships displaced wooden sailing ships because technological change and falling prices of British iron caused the supply curve of iron ships, and ship prices, to fall relative to the supply curves of wooden ships.[26]

Technological change, factor prices and wage rates all played an important role in the diffusion of iron ships. These factors, along with demand conditions, are examined in relationship to the diffusion of the tractor in chapter 3. The farming industry was characterized by competing techniques for many years. It too may have been in a state of "competitive equilibria."

Diesel Locomotive

Diesel locomotives began to displace the steam locomotive in 1924 in the United States.[27] Mansfield notes that, "The early diesel locomotives were heavy, slow, and without much power."[28] He also states that the early diesel locomotives were ". . . usually installed where there was a smoke nuisance or a fire hazard."[29] Mansfield's primary objective in this

study is to determine the intrafirm rates of diffusion. In discussing the historical development of the diesel locomotive, Mansfield says that there were significant improvements made in the locomotive which made it more profitable relative to the steam locomotive.[30] The locomotive was much improved by technological changes during the years 1924 to 1950. By the year 1959, the diesel locomotive had nearly completely replaced the steam locomotive.[31]

Mansfield hypothesized that the rate of the intrafirm diffusion depended primarily upon four variables. These were the profitability of the innovation, the riskiness of the innovation, the size of the firm, and a measure of the firm's liquidity. The profitability of the new techique is undoubtedly of major importance. Mansfield does not attempt to measure of the factors involved in the profitability of the diesel locomotive and in his model he assumes that the rate of return is constant. The liquidity of the firm is also important for finance reasons. This would be especially true for large investments, such as the diesel locomotive. The riskiness of the new technique would also tend to delay the adoption of the technique. Mansfield assumed that this declined through time. Mansfield found that all the independent variables were significant except for the size of the firm.

In another study, Mansfield examines the firm's decision to initially adopt an innovation. Diesel locomotives were also a part of this study. He found that the adoption rate depended

primarily upon two variables. One was the profitability of the innovation. The other was the size of the investment.[32] A technique requiring a large investment would be examined more carefully and would be more difficult to finance. This may be a large concern of the smaller firms when confronted with an expensive new technique.

Mansfield examined several variables that determined the rate of adoption of the diesel locomotive. It was found that the ability of firms to finance new techniques was significant. A variable to approximate the farmers' ability to finance the tractor is examined in chapter 3.

Motorship

A recent study of the diesel ship (motorship) yields some very interesting analysis of the diffusion process.[33] In this case, the new technique was the motorship and the technique that it was replacing was the steam vessel. The motorship was first adapted for marine propulsion in 1902.[34] The motorship contributed 33% of the total cargo liner fleet in Great Britain in 1939.[35] The adoption rate in Great Britain was slow relative to other countries in Europe. Henning and Trace sought to determine if the slow adoption rate was economic or whether the British shipowners should have adopted the motorship faster.

Henning and Trace attempted to calculate the cost and benefits of the motorship compared to the two types of steam vessels being built in 1922. During the inter-war period, many of the British shipowners replaced many of their older

steam vessels for newer steam vessels. At the same time, many other shipowners in other countries replaced their steam vessels with the motorship. To determine the relative advantage of the motorship to the steam vessels, Henning and Trace used the following model:

> We have chosen to investigate these decisions using the discounted cash flow technique. In investigating the optimal type of vessel to be built by an owner interested in replacing war losses or increasing capacity, we have calculated costs and revenue on a voyage basis for three hypothetical cargo liners of approximately 8000 gross register tons (g.r.t.), assumed to have been built in 1922 and to have entered service in early 1923. Vessel A is powered by diesel, vessel B by a oil-fired, reduction geared steam turbine, and vessel C by a coal-fired, reduction geared steam turbine . . . Included in voyage costs are estimates of capital costs, crew cost, (wages, victualling and repairs, port charges, canal dues, stevedoring and cargo handling and administration . . . By subtracting costs from revenues, and translating the voyage cash flows into an annual basis, we compute the 'net cash flow' for each year of each vessel's life.[36]

With the use of the preceeding assumptions, Henning and Trace found that the motorship was definitely the more profitable technique to adopt. They concluded that the British shipowners were slow in adopting the new technique.[37]

In a convincing way, Henning and Trace show that the British shipowners continued to use the steam vessels many years after the motorship was more profitable. In attempting to understand the reasons for the delayed adoption of the motorship, they examined the supply and demand conditions to determine what caused this slow diffusion. Three things were examined. They were technological changes, the supply of skilled labor and factor prices of coal and oil. Technological

changes occurred in both the steam vessels and the motorship. Henning and Trace stated that the success of the motorship ". . . acted as a spur to the design of the marine steam engine and during the remainder of the inter-war years a succession of innovations and modifications improved the efficiency of both steam and diesel installations."[38] They argue that despite the improvements of the steam vessel that the motorship improved its relative position.[39] The supply of skilled labor to operate the new diesel ship may have caused some delay in adopting the new technique, but Henning and Trace see little evidence to support this position.[40] The future factor prices of oil and coal were probably the primary factor that caused the delayed adoption of the motorship. Many British shipowners expected that the price of oil would rise relative to the price of coal. They state the ". . ., shipowners in the early twenties appear to have been concerned about the changes in the relative price of coal and oil fuel.[41] While this seemed like a rational behavior, the fact was that it was oil that decreased relative to coal. These are the major factors that delayed the adoption of the motorship. The adoption of the motorship appears to be a case where there were economic incentives to adopt the new technique, but because of additional factors there was a significant lag in its adoption throughout the shipbuilding industry.

Henning and Trace calculated the relative costs of steamships compared to the motorship. They also examined supply and demand conditions that may have affected these costs. The diffusion of the tractor will be studied similarly in chapter 3. The costs of using the tractor will be directly compared to the costs of using the horse. Both changing supply and demand conditions will be examined in relationship to this cost comparison. The techniques employed by Henning and Trace to study the diffusion of the motorship should prove useful in the study of the diffusion of the tractor.

Reaper

The final case study to be examined is that of the diffusion of the reaper. Two economists have made a study of the reaper and have reached different conclusions as to the determinants of the rate of adoption of the new technique.[42] The diffusion of the reaper has an interesting history. David summarizes this history:

> From 1833, the date of the first sale of Obed Hussey's reaping machine, to the closing year of that decade, a total of forty-five such machines had been purchased by American farmers. At the end of the 1846 harvest season . . . previous sales of all reaping machines at that time aggregated to a mear 793, but by 1850 some 3373 reapers in all had been produced and marketed in the United States since 1833. A scant eight years later it was reckoned that roughly 73,200 reapers had been sold since 1845, fully 69,700 of them since 1850. And most of that increase had resulted from the burst of production enjoyed by the industry during the five years following 1853![43]

Both economists have reached the conclusion that the profitability of the reaper increased greatly after 1845. The disagreement occurs in explaining the sudden increase in profitability.

David explains the increased profitability of the reaper on relative factor prices and the increase in the size of the average acres of grain harvested. David constructs a model that attempts to measure a "threshold" point in the number of acres of grain. This is constructed by measuring the relative prices of labor to the reaper.[44] The reaper was less labor-using. When the cost of labor decreased relative to the capital costs of the reaper, the threshold size diminished. The reaper also enjoyed economies of scale that the older labor-using technique did not. In the years from 1849 to 1853 the ". . . purchase of a reaper was equivalent to the hire of 97.6 man-days labor with the cradle . . . it is seen that these factor prices established a threshold level at 46.5 acres of grain.[45] During this same period, David states that the average acreage devoted to grains was 25.[46] During the mid-1850's, David notes a change in these conditions. In the ". . . period 1854-7 a McCormick reaper cost the farmer, on the average, the equivalent of only 73.8 man-days of hired cradlers' labor, . . .[47] The change was caused by a shift in the relative factor prices of the reaper and labor. During this same period the average acreage devoted to grain increased to 30. Because of the change in relative factor prices, the new threshold in the years from 1854 to 1857 was approximately 35 acres of grain planted.[49] David concludes that the reasons for the rapid adoption of the reaper in the mid-1850's ". . . should thus be told in terms of the effects of both an expansion of grain acreage

sown on individual farms and the downward movement of the threshold size as a result of the rising relative cost of labor.[50]

In another study of the diffusion of the reaper, Olmstead sharply criticizes the findings of David. Olmstead finds two major problems with David's paper. One of these was David's assumption that there were no productivity increases in the reaper. The other was David's assumption that reapers were not shared or rented. Olmstead emphasizes the two points. He states that, "First, sharing and contracting were economically feasible and widely practiced. Second, a myriad of improvements in reaper design profoundly affected machine productivity and diffusion."[51] One way that David's threshold could be reduced is through sharing and contracting. Olmstead examines records and diaries of farmers and has convincingly shown that contracting and sharing was widespread during the introduction of the reaper. Olmstead then directs his study towards the technological changes or secondary invention to the early reaper. Olmstead reports that there were many significant improvements made to the reaper. Some of these were an improvement to the cutting bar, a better knife design that led to specialized mowing machines, improvements in the draft of the reaper and changes which kept the reaper from clogging. Olmstead reports that in 1848, judges from the New York State Agriculture Society found that ". . . all the machines clogged badly, were extremely heavy,

and had excessive side drafts. The judges rated the machines' overall performance and the quality of their work below that done with a scyth or cradle."[53] He states that the judges, four years later, were much different. During this testing of the reapers, they were much more impressed with the reapers, suggesting that important changes did occur during those four years.[54]

Olmstead concludes that the reaper was, in fact, divisible and that sharing and contracting did occur. This weakens David's threshold model. Olmstead then argues the following:

> Changes in relative factor prices as emphasized in the comparative static model undoubtedly contributed to diffusion. Tradition historians recognized this point, but they considered it of minor importance compared to the effect of changing technological factors on diffusion - to date not one iota of evidence has been offered that seriously challenges this judgment . . . The proper parable for the reaper is not the story of Archimedes in the tub shouting 'Eureka' but the tale of the ugly duckling.[55]

The study of the adoption of the reaper and the study of the adoption of the tractor are common in many respects. Both Olmstead and David attempted to determine the causes for the increasing rate of adoption of the reaper. They found technological advances, wage rates, acres of land, and other supply and demand variables important. These same factors may also be important in the study of the adoption of the tractor and will be examined in the following chapter.

Summary of the Economies of Diffusion

The case studies of hybrid corn, shipbuilding, the diesel locomotive, the motorship, and the reaper examined the rate of diffusion of a new technique. Each of the five studies analyzed the rate of adoption differently, but a common determinant of technological changes that runs through all of the analysis is the profitability of the new technique. Each study considers the firm or individual as a profit maximizer. A new technique will not be adopted until it is perceived profitable to do so. While this is a necessary condition, it may or may not be a sufficient condition. The study of the rate of diffusion of any industrial technique means that the determination of the point of profitability of that new technique is examined. In addition, both the demand and the supply conditions of the industry need to be analyzed to determine why it reaches the point of profitability. As can been seen from the case studies, different techniques have quite different histories.

A major controversy that runs through the economic literature is the importance of supply conditions versus demand conditions in determining the rate of adoption. It is entirely possible and probable that each is significant. One may be more important in one technique, while the other is more important in a different technique. It can only be said that to fully examine the diffusion of any technique it would be advised to analyze both the supply and demand conditions in the industry.

The case studies have thrown some light upon how the firm or individual determines the point of profitability of the new technique. The case with hybrid corn illustrates a simple decision-making process. Corn seed needs to be supplied every year. There was little difference in price between the two types of seed. The primary decision that needed to be made was whether or not the hybrid corn was more productive. The other case studies illustrated that the decision to adopt the new technique may be more complex. One of the more important findings is that scrapping and adoption decisions were not clearly separated in many cases. The decision to adopt a new technique generally was part of a replacement decision.

While the profitability of the new technique is the primary determinant of the adoption rate, there are other reasons that may increase or decrease that rate. Things such as lack of finance, uncertainty, labor oppositions, ignorance of management, and patent laws all can delay the adoption of new techniques that are profitable. Lack of finance may affect the smaller firms in the industry. Many of the new techniques that are produced are large capital investments that can only be financed through large companies. Uncertainty about the technology can cause delay. In the case of the motorship, the employers were uncertain that the new diesel engine would be profitable. This is especially true when the new technique is only slightly more productive than the older technique. It is difficult to determine which technique is

more profitable. Uncertainty about the future can also play an important role. The motorship may have been adopted faster if the firms were not concerned about future supplies of oil. Labor opposition has been a cause of delay in the adoption of some techniques. These have traditionally been labor-saving techniques that have displaced workers. While these efforts have been effective in the past, labor opposition to new techniques has been declining in recent years. Poor management can decrease the adoption rate. Patent laws are a major reason for the slow diffusion of technology. Patents can last many years, depriving other firms or individuals of access to these new techniques.

The review of the literature of diffusion in economics has shown an overwhelming concern with the profitability of the new technique. Other variables received little attention. If profitability is the key variable to determine the rate of adoption of a new technique, then both the point of profitability and changing supply and demand conditions must be examined. There are other economic variables that may be important. These may or may not be important in any one case, but should be examined along with the anthropological and sociological variables.

Chapter 2--Notes

1 Ralph Linton, The Study of Man (New York: D. Appleton-Century Company, 1936), p. 341.

2 Ibid., pp. 341-42.

3 Ibid., p. 342.

4 H. G. Barnett, Innovation: The Basis of Cultural Change (New York: McGraw-Hill Book Company, Inc. 1953), p. 16.

5 Linton, p. 308.

6 George M. Beal and Joe M. Bohlen, How Farm People Accept New Ideas, North Central Regional Publication no. 1, Special Report no. 15, Iowa State College, Ames, Iowa, November 1955; also in Everett M. Rogers, Diffusion of Innovations (New York: Free Press, 1957), p. 119.

7 George M. Beal and Joe M. Bohlen, pp. 3-4.

8 Eugene A. Wilkening, "The Process of Acceptance of Technological Innovations in Rural Society," in Rural Sociology: An Analysis of Contemporary Rural Life, ed. Alvin L. Bertrand (New York: McGraw-Hill Book Co., Inc., 1958), p. 388.

9 Ibid., p. 392.

10 George M. Beal and Joe M. Bohlen, p. 8.

11 George M. Beal and Joe M. Bohlen, The Diffusion Process, Iowa Agr. Exp. Sta. Special Report 18, Ames, Iowa, 1957, pp. 4-6.

12 Ibid.

13 Everett M. Rogers, p. 283.

14 These factors were primarily developed in Harry Jerome, Mechanization in Industry, National Bureau of Economic Research publication, no. 27 (New York: National Bureau of Economic Research, 1934), pp. 326-364; in Richard R. Nelson, Merton S. Peck and Edward D. Kalachek, Technology Economic Growth and Public Policy (Washington, D.C.: The Brooking Institution, 1967), pp. 99-105; and also in Edwin Mansfield, Industrial Research and Technological Innovations: An Econometric Analysis (New York: W. W. Norton and Co., 1968), pp. 155-191.

Chapter 2--Notes

15 Zvi Griliches, "Hybrid Corn and the Economics of Innovation," in The Economics of Technological Change, ed. Nathan Rosenberg (Middlesex, England: Peter Smith, 1971; Penguin Books, Ltd., 1971), pp. 221-28.

16 Ibid., p. 215.

17 Ibid., p. 219.

18 Ibid., p. 221.

19 Ibid.

20 Ibid.

21 Ibid., pp. 221-22.

22 C. K. Harley, "On the Persistence of Old Techniques: The Case of North American Wooden Shipbuilding," Journal of Economic History 33 (June 1973): 372-98.

23 Ibid., p. 372.

24 Ibid., p. 373.

25 Ibid., p. 387.

26 Ibid., p. 388.

27 Edwin Mansfield, Industrial Research and Technological Innovation: An Econometric Analysis, p. 174.

28 Ibid.

29 Ibid.

30 Ibid., pp. 175-77.

31 Ibid., p. 177.

32 Edwin Mansfield, "Technical Change and the Rate of Imitation," in The Economics of Technological Change, ed. Nathan Rosenberg, p. 310.

33 Graydon R. Henning and Keith Trace, "Britain and the Motorship: A Case of the Delayed Adoption of New Technology?" Journal of Economic History 35 (June 1975): 353-85.

34 Ibid., p. 353.

Chapter 2--Notes

35 Ibid., p. 358.

36 Ibid., pp. 369-70.

37 Ibid., pp. 371-77.

38 Ibid., p. 384.

39 Ibid.

40 Ibid., p. 383.

41 Ibid., p. 382.

42 Paul A. David, "The Mechanization of Reaping in the Ante-Bellum Midwest," in _The Economics of Technological Change_, ed. Nathan Rosenberg; and Alan L. Olmstead, "The Mechanization of Reaping and Mowing in American Agriculture, 1833-1870," _Journal of Economic History_ 35 (June 1975): 327-52.

43 David, pp. 234-35.

44 Ibid., p. 248.

45 Ibid., p. 251.

46 Ibid., p. 252.

47 Ibid., p. 253.

48 Ibid., p. 254.

49 Ibid., p. 253.

50 Ibid., p. 254.

51 Olmstead, p. 328.

52 Ibid., pp. 334-44.

53 Ibid., p. 349.

54 Ibid.

55 Ibid., p. 352.

CHAPTER 3

THE DIFFUSION OF THE TRACTOR

The Problem

During the last decade of the nineteenth century and the first few decades of the twentieth century, there was a revolution in the type of power used on the farm. Animal power and manpower had been the predominant source of power in agriculture for centuries. It was not until the second half of the nineteenth century that mechanical power became available on the farm. The first type of mechanical power was the portable steam engine that was used as early as 1849.[1] Gradually, these steam engines were developed into self-propelled steam traction engines. While these steam traction engines could be operated efficiently for certain types of farm work, the engines possessed handicaps that could not be overcome. As one historian of the steam traction engine stated, "The engines were powerful enough, but they were also ponderous in size, clumsy to operate, and too heavy to handle on unfavorable ground or rough terrain. To get power and traction, the steam engine designers could not get away from the problem of weight."[2] These problems with the steam traction engine led to the development of the internal combustion traction engine or the tractor, beginning in 1892 with the gasoline tractor built by John Froelich.[3] It is the development and diffusion of the tractor that this study seeks to explain. The development and diffusion of the tractor revolutionized farming in the United States. It was a major

step in bringing the industrial revolution and mechanical technology to the farm. While the steam traction engine began the substitution of mechanical power for animal and manpower, it was the tractor that completed this transition.

The development of the tractor provides an interesting case study of technological change in the first decades of the twentieth century. The tractor as a new technique in farming competed with both the steam traction engine and the animal power that was still used on the vast majority of the farms. The transition to tractor power was a slow process. Steam traction engines competed strongly with the tractors during 1910-1920.[4] These engines were still being manufactured by major companies up to 1925.[5] But even both these machine technologies did not completely replace animal power which persisted well into the 1940's and even longer in certain areas. The substitution of tractor power for animal power occurred slowly in the twentieth century. In 1910, there were only about 1,000 tractors on the farms of America.[6] In 1910, there were 6,407,000 farms which figures to only .00016 tractors per farm.[7] By comparison, there were 23,321,000 horses and mules per farm in 1910.[8] There was much activity in the development of the tractor during this period and before, but few farmers used the tractor to supply power to their farms. Figure 3 illustrates the rates of diffusion of both animal power and tractor power from 1910 to 1950.[9] It is evident from the graphs showing tractors per farm and horses (mules) per farm that tractor power gradually

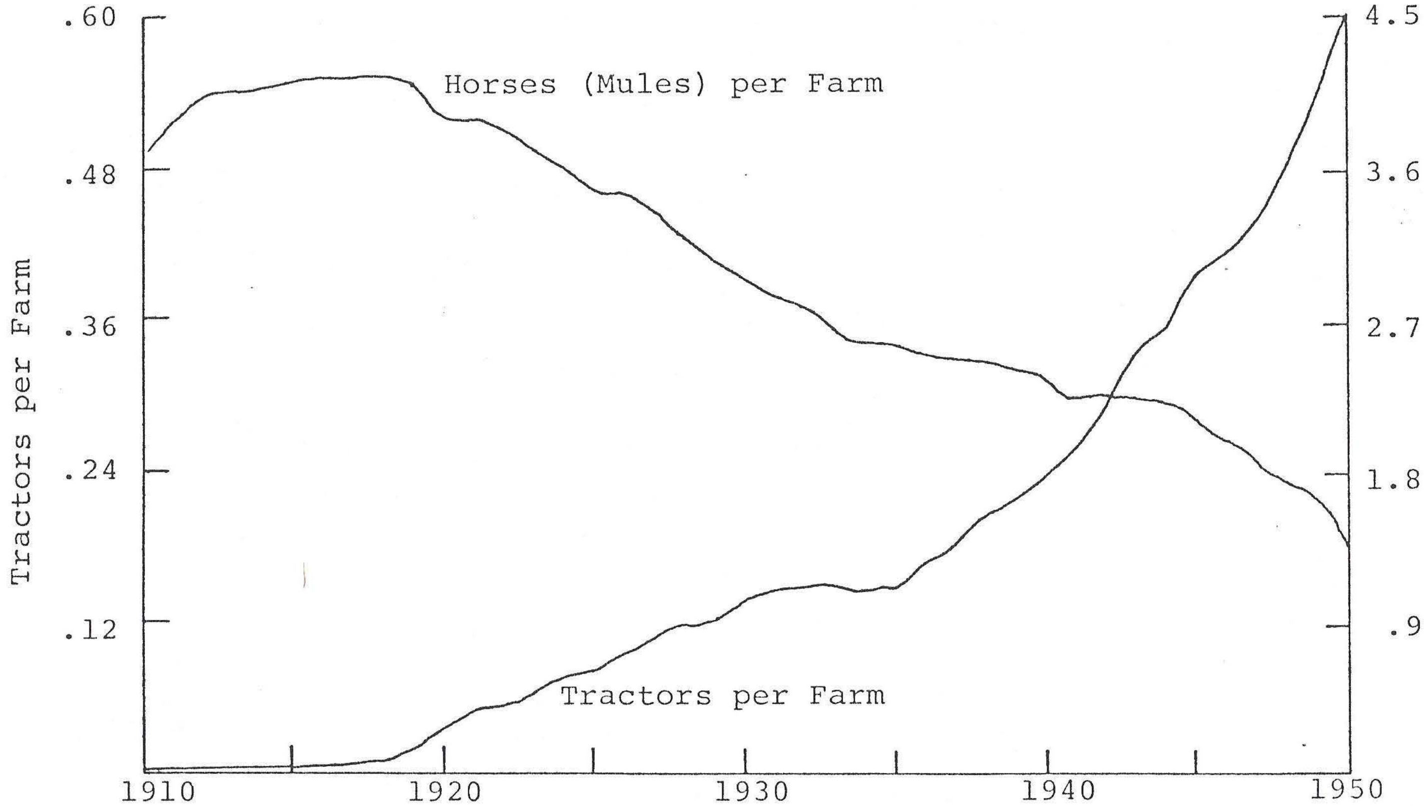

Fig. 3.--Tractors and horse (mules) per farm, 1910-1950. ADAPTED FROM: Number of tractors and farms--U.S. Department of Commerce, Bureau of Census, Historical Statistics of the United States: Colonial Times to 1957, pp. 278-285; Number of horses--U.S. Department of Agriculture, Agricultural Statistics 1957, p. 440.

replaced animal power on the farm during the twentieth century. The upsurge in tractor acquisition began between 1918 to 1921. There was a steady increase of tractors until the Great Depression. During the worst depression years, the number of tractors per farm actually declined slightly, but the main result of the depression was a six year lag in the adoption of tractors. From 1936 to 1950, there was a steady increase in the use of tractors. The opposite trend is true for the number of horses (mules) per farm. There was a peak of 4.12 horses (mules) per farm in both 1917 and 1918. This number was reduced to 1.35 in 1950.

The problem is not an understanding of the fact that the new invention of the tractor replaced horses (mules) as the primary source of power on the farms. The problem is understanding why the diffusion of the tractor took as long. The tractor was invented in 1892 but animal power was used on farms into the late 1940's and later in some locales. There are two possible explanations for the slow rate of adoption of the tractor. One is that the farmer behaved irrationally and delayed adoption because of ignorance or inertia. The other explanation is that the farmer acted rationally and delayed adoption because of lack of comparative advantage or compatability. If the farmer did act rationally, there is a need to determine the conditions that caused the adoption of the tractor. While specifically looking at the question of profitability, it should be asked

whether or not technological change was delayed for non-economic reasons. What cannot be explained in economic analysis may be explained with non-economic analysis.

Making the assumption that farmers view utility primarily in profit maximizing terms when considering the adoption of a tractor, Robert Higgs hypothesises that a change in technique will occur when that change reduces total costs.[10] He states that total costs will be reduced because of: (1) the technical superiority of the new technique, (2) the relative prices of the capital equipment required to implement the alternative techniques, and (3) the wage rate of labor.[11] These are the most obvious explanations for a shift in technique. These and other factors are examined as either changing supply or demand conditions of the new technique. Changing supply conditions include secondary inventions associated with the new or old techniques, greater efficiencies in the production process, economies of scale of production, supply of skilled labor and material for production and the supply of marketing and repair outlets. Changing demand conditions include factor prices of products used to operate the techniques, economies of scale of operation, uncertainty, supply of labor and materials to operate techniques and other individual aspects of demand such as income, taste or prices of other goods.

The analytical and empirical part of the paper is developed in three sections. The first section undertakes an analysis of changing supply conditions. This section includes

a historical development of the tractor and a general discussion of relevant supply conditions. The second section examines changing demand conditions. This section includes a general discussion of relevant demand conditions and an empirical study on the importance of farm wages, the value of land and the size of farms from the years 1920 to 1950. The third section analyzes both the usefulness and cost of farming with tractors and farming with horses (mules). This section contains a comparison between the two types of techniques and an analysis of changing supply or demand conditions that affected the costs of these techniques. The study examines this diffusion process for all the states excluding Alaska and Hawaii.

Supply Conditions

Historical Development

In the years preceeding the invention of the tractor, the main sources of mechanical power on the farm were the portable steam engine and the steam traction engine. These steam engines were primarily used for threshing, although the steam traction engine was also used for plowing.[12] The steam traction engine had several disadvantages that encouraged attempts to develop an alternative to steam power. One of the major disadvantages was the problem of weight. The steam traction engine often weighed more than 45 thousand pounds.[13] The weight of the steam traction engine made it unsuitable for some types of terrain. It caused excessive packing of the soil, made it hard to handle and resulted in high-priced machines.

Another major disadvantage was the size of the crews needed to operate such machinery. A description of a typical crew for the steam traction engine is as follows:

> Such crews included two men to operate the steam engine, two to haul coal and water, two to operate the thresher, a waterboy, and several men to haul bundles to the thresher and the grain away by horses and mules.[14]

This may have been the most important reason for the development and success of the tractor. Wik states that "A one-man tractor outfit, dispensing with the high-priced services of the assistants on the steam engine crews, appeared to be the strongest arguments favoring the introduction of gasoline power to agriculture."[15] Other disadvantages of the steam traction engine were the danger of explosions, lack of water or fuel in certain locales, freezing of water pipes and time lost in getting up steam.[16] All of these problems with the steam traction engine made the conditions ripe for the development of the tractor.

The development of a practical internal combustion engine to replace the steam engine was a slow process. Not until Edwin Drake drilled his first oil well at Titusville, Pennsylvania, in 1859 was there a satisfactory fuel for the internal combustion engine.[17] "The absence of an adequate fuel rather than a dearth of first-rate inventive ability was doubtless the major reason for the slow development of the gasoline engine."[18] Less than two decades after the beginning of the petroleum industry came the development of a practical internal combustion engine. This was the

engine developed by Nicholas Otto. By 1876, the Otto Company of Philadelphia secured a virtual monopoly of the basic patents on this type engine.[19] Not until these patents expired in the early nineties did other companies make an effort to develop and manufacture these engines.

It was in the early nineties that the gasoline tractor first became operational. The invention of the tractor is credited to John Froelich of Froelich, Iowa, in 1892. The first description of this tractor is as follows:

> The engine proper was built by the Vanduzin Gasoline Company, of Cincinnati, Ohio, to order of John Froelich, of Froelich, Iowa, who built the traction for it and made some improvements in feeding the gasoline to the engine. The engine is of the vertical type, thereby overcoming the end motion caused by the piston of the horizontal engines. Its cylinder is 12x14, and rates thirty h.p. indicated, or twenty actual h.p. Its weight is, completely, nearly 9,000 pounds, or about two-thirds the weight of a fourteen h.p. steam traction engine, when steamed up.[20]

This tractor completed fifty days of threshing of 62,000 bushels of grain and seed operating in temperatures from 100 degrees Fahrenheit to -3 degrees Fahrenheit.[21] The tractor built by John Froelich needs to be put in proper perspective. While it is considered to be the first tractor ever built, it must be recognized that this tractor was little else than a gasoline engine being placed on a steam traction engine framework. The development of the tractor had begun, but it had a long road ahead before it developed into an efficient mode of power on the farm.

Experimentation with tractors continued throughout the 1890's and early 1900's. These experiments generally were of the same type as those of John Froelich. Companies attempted to replace the steam engine with new and better types of gasoline engines. Some were successful but most were failures. All still used the steam traction engine's framework as the basic starting point. The result was many of the same disadvantages as with the steam traction engine. Very few tractors were sold for the first decade of tractor development. The first successful tractors built in the United States were the Hart-Parr engines produced in 1902 and 1903.[22] The Hart-Parr tractors performed well and were more reliable than many of the other tractors in this era. The early models of many inventions are crude and are in need of many secondary inventions and improvements. Farmers were hesitant to make large capital outlays on tractors that were unreliable. A reliable tractor that performed reasonably well could be sold. This was the type of tractor that Hart-Parr manufactured. "The first Hart-Parr engine was run for seventeen years by an Iowa farmer, while five of the fifteen built in 1903 were still in operation in 1930."[23] The Hart-Parr line of tractors was the first business in the United States solely devoted to the manufacture of tractors.[24] In 1907, there were about 600 tractors in use in the United States, one-third of which were Hart-Parrs . . ."[25] The Hart-Parr tractors dominated the tractor industry in the first decade of the twentieth century. The tractor was

still in its early developmental stages. It resembled the steam traction engine in every way except for its engine. The steam traction engine did not die with these early improvements of the tractor but still dominated the primary source of mechanical power on the farm. The Hart-Parr tractors, with improved performance and reliability, were one of the first major indications that the tractor could compete with the steam traction engine. But animal power and manpower were by far the most common way to supply power on the farm and continued to be for many years.

Tractors manufactured before 1913 generally resembled the steam traction engines. A more detailed analysis of these earlier tractors is necessary to understand the improvements that were made during the next quarter of a century. The primary disadvantage with the tractor was the problem of weight. Wik describes the early tractor:

> These machines appeared on the market weighing twenty to fifty thousand pounds, unwieldy creatures that broke down as frequently as they ran, and dug their ponderous selves into countless mudholes in the farm lands of the West. The flywheel alone on some of the tractors, weighed over a ton.[26]

Some of these tractors had tanks which held as much as one hundred gallons of water, seventy-five gallons of gasoline, and five gallons of oil.[27] This period is rightly called the era of the large tractor. The important components of a successful tractor were being developed. Many of these tractors had automatic intake valves, hit-and-miss governors and make-and-break ignition systems.[28] Electric current for

the ignitions was generally supplied by dry batteries for starting and a direct current magneto or a generator.[29] The ignition and starting systems were far from perfected. It was reported that some of these tractors were so difficult to start that the owners of these machines let them run all night rather than attempting to do so each morning.[30] "The instruction manual of the Hart-Parr Company listed nineteen rules to follow in starting the engine and thirteen rules for stopping it."[31] The farmer needed the talents of an engineer and a mechanic for the operation of the tractor. The other parts of the tractor similarly lacked perfection. The frames were built of channel iron, which was the primary factor involved in the great weight of the tractor. The drive gears were made from cast iron and because they were exposed to the dust and dirt, wore rapidly.[32] Many of the tractors only had one forward gear.[33] The farmer had these problems to consider before the purchase of a tractor. Many of the companies producing tractors were new and unknown. The farmer might find a bargain or a disaster in the purchase of a tractor. Wik relates an interesting passage from the owner of a Hart-Parr tractor in 1908:

> I have done everything possible to make our engine work. We hired the most competent engineer in the state, yet we had all kinds of accidents and trouble. I don't know what to do. We have run the engine less than thirty days but our expenses are so great that I am ashamed to meet the public. Steam engine men warned me that we would be in for big repair bills.[34]

This first period in tractor development was primarily concerned with the replacement of the steam engine with the gasoline engine. The further development of the tractor needed new ideas and secondary inventions. Tractors and steam traction engines fulfilled the same need of the farmer. It was in the second period of tractor development that tractors were differentiated from the steam traction engine. This period started by the introduction of the first frameless type tractor.[35] The Wallis "Cub" was the first tractor to introduce this type of construction.[36] The frameless design used a one piece U-shaped boiler plate steel crankcase and the transmission housing provided the backbone of the machine.[37] The design allowed a more compact tractor and eliminated the need for heavy channel iron framework. Its crankcase and transmission housing enclosed many of the moving parts that had been exposed to the dirt and dust. The new design enclosed all ". . . moving parts in the transmission train, except the final drive gears, and it was but a logical step to the development of live-axle models with all gears enclosed."[38] There was another tractor that was introduced in 1913 that began a revolution in tractor design. The Bull tractor, manufactured by the Bull Traction Machine Company of Minneapolis, and advertised as "The Bull with a Pull,"[40] started the trend towards smaller tractors. It had a 12 h.p. engine compared with many other tractor engines that were producing 40 to 65 h.p.[41] It was a development and innovation

with which steam traction engines could not compete. The steam traction engines were doomed by their monstrous size. The trend towards smaller tractor units is seen in the fact that in the following year, the Bull Traction Machine Company ranked first in tractor production.[42] The Ford Motor Company started production of the Fordson in 1917.[43] The Fordson was a small frameless type tractor. Its frameless type construction was not made of boiler plate steel as was the Wallis Cub but was made of cast iron which lessened the weight of the tractor.[44] "This frame-type construction was so practical that most tractor manufacturers soon adopted the idea in the construction of their own procucts."[45] Both the frameless tractor and the smaller sized tractors were fundamental changes in the design of the tractor. These were changes that would be incorporated into the successful tractor a few years later.

There was another significant improvement to the tractor made in 1918. This was the power take-off developed by the International Harvester Company.[46] The power take-off permitted ". . . direct transmission power from the engine to such equipment as mowers, small combines, and sprayers.[47] Most other tractor manufacturers soon followed International Harvester's example in producing the power take-off. This was another step in the process of making the tractor more versatile and useful to the average farmer at a price affordable to the average farmer.

The 1920 tractor was improved in comparison to the tractor at the beginning of the twentieth century. Gray and Dieffenbach describe the 1920 tractor in the following words:

> From the standpoint of the development, the 1920 tractor taken collectively, embodies fundamental engineering and designing found perhaps in more refined form in tractors of the present day. The one-piece cast iron frame, replaceable wearing parts, force-feed and pressure-gun lubrication, enclosed transmission, carburetor manifolding, air cleaner, electric lighting and starting, the high-tension magneto iginition with impulse starter, enclosed cooling system, antifriction bearings, alloy and heat treated steels, and the power take-off had all been introduced, and some experiments had been made with rubber tires. The lightweight, low-priced tractor had been designed and widely accepted, and several fairly successful motor cultivator type units were on the market.[48]

There were major improvements made during the 1920's. Development in 1920 emphasized versatility. In 1924, the International Harvester Company produced the Farmall, which was the first successful all-purpose tractor.[49] It was designed by Bert Benjamin, who not only had the knowledge of an engineer and designer, but had the knowledge of a farmer necessary to develop a successful general purpose tractor.[50] Benjamin developed the Farmall with the farmer in mind. Previous tractors were designed for plowing and other drawbar work but were not very useful in row-crop cultivation. Benjamin's aim was to ". . . adapt the standard tractor design to suit the vast acreage of row-crop cultivation in the American corn belt and elsewhere.[51] The tractor itself had front wheels mounted close together with two large wheels in the back, high ground clearance for the purpose of working over crops, good visability and maneuverability, well designed connections

for a variety of implements which could be mounted behind, beneath, or in front, and differential or steering brakes which allowed the tractor a small turning radius.[52] The development of the Farmall tractor ". . . probably did more than any other advancement to broaden the usefulness of the tractor, and thus to further mechanization on the farm."[53]

In 1929, Deere and Company produced a general purpose tractor that was similar to the Farmall. One further development incorporated into this tractor was a mechnical power lift.[54] This mechanical lift could raise and lower mounted implements, making the tractor more useful and versatile.

The United States was in the midst of a depression in the 1930's and tractor companies were hesitant and unable to devote much time to the development of new tractor models. There were two significant developments that occurred within this time period. One was the introduction of low-pressured pneumatic tires. The other was the introduction of the three point hydraulic hitch, designed by Harry Ferguson.

The Goodrich Company, in 1931, developed a low-pressure pneumatic tire.[55] Other tire companies soon began to experiment with this tire. The Allis-Chalmers Model U tractor was the first tractor to be fitted with these new low-pressure tires in 1932.[56] The tires were produced by the Firestone Company and designed to be inflated to 15 lbs.

pressure.[57] These tires were both a relief to the farmer and an innovation that increased the efficiency of the tractor. Gray and Dieffenbach make note of the advantages derived from using the pneumatic tire:

> These tires proved advantageous in several ways: they effected easier riding, they reduced vibration and caused less wear on tractor parts, they permitted higher field and road speeds, they reduced rolling resistance, and they effected more efficient operation.[58]

Experimentation with the use of water inside these pneumatic tires for increased weight and traction began in the mid 1930's.[59] This too increased the efficiency of the rubber tire. The advantages of the pneumatic rubber tires were soon recognized. In 1934, only 14% of tractors manufactured were with rubber tires.[60] In the year 1940, 85% of the tractors came equipped with the new tires.[61]

The last major secondary invention of the 1930's was the three point hydraulic hitch developed by Harry Ferguson in Ireland and imported to this country in 1939.[62] It was brought to this country on an agreement between Henry Ford and Harry Ferguson.[63] The three point hydraulic hitch revolutionized implement control. This hydraulic system could control implement depth. It allowed the farmer much greater control over the implement use and again increased the efficiency and usefulness of the tractor. "It was a revolutionary easy method of implement control - so much so that the whole trend of design of farm tractors and equipment in the ensuring years has been greatly influenced by the appearance of the Ferguson System."[64]

The primary tractor innovations were developed by the year 1940. World War II curtailed most research and development on the tractor until 1946. Some development did occur within this period however. One was the development of tractors designed to burn LP (liquefied petroleum) gas, which is the light end of crude oil.[65] The main advantages of LP gas compared to gasoline is that it burns cleaner and causes less oil dilution.[66] Another similar development in American tractors was the development of diesel burning tractors.[67] These made the tractor more efficient for some purposes. The farmer could choose the tractor that burned the fuel most suited to his needs. The most important development that occurred in the 1940's was the introduction of the continuous running power take-off. Dieffenback and Gray notes the significance of the power take-off:

> Hereafter, machinery operated by the regular power takeoff [sic], such as sprayers, drawn cornpickers, and combines, would stop when the clutch was released. The continuous running power takeoff [sic] allows one to stop the travel of the tractor without stopping the power takeoff [sic].[68]

It was designed and sold by the Cockshutt Plow Co. in Brantford, Ontario, in 1947.[69]

This history shows that the tractor of 1892 was not the tractor of 1950. Major innovations made the tractor much more efficient, reliable, and useful throughout the years.

Other Supply Conditions

There are other factors affecting supply that are important to examine. These are innovations in the old techniques of obtaining power on the farm, greater efficiencies in the production processes, factor prices of products used in the production processes, economies of scale of production, the supply of skilled labor and materials for production, and the supply of marketing and repair outlets.

While improvements in the tractor were being made, there were also improvements in both the technique of power farming with the steam traction engine and the technique of power farming using animal power. These seem to play minor roles in the slow diffusion rate of the tractor. The steam traction engine did improve until it was discontinued in the 1920's and continued to have a significant share of the market into the 1920's. The tractor inherited many of these improvements during the early years of tractor development. It does not appear that innovations in the steam traction engine had a significantly negative effect on the diffusion of the tractor.

Innovations in the technique of farming using power provided by animal power also does not appear to have had a major impact on the slow diffusion rate of the tractor. Improvements were made in the implements pulled by the horse (mule) and there were improvements in breeding techniques. Improvements in the implements used by this technique were much outnumbered by improvements made in implements used by the tractor. New

breeding techniques may have increased the efficiency of the animal power but certainly did not do so to a great extent. These would have the effect of slowing the diffusion rate of the tractor. It was this power source that the tractor took so long to displace, but the reason for this slow displacement does not appear to be innovations of farming with animal power.

Greater efficiencies in the production processes, economies of scale, and the supply of marketing and repair outlets in the production of the tractor significantly increased the diffusion rate of the tractor. The result was lower production costs and better service. The classic example of the importance of these factors occurred when Henry Ford entered the tractor industry with the production of the Fordson. Henry Ford not only revolutionized the automobile industry but brought the same type of technology to bear in the tractor industry. The man who made the low-priced automobile available to the general public produced a low-priced tractor available to the farmer.

Ford's entry into the tractor industry was dramatic. The original Fordson sold for $750.00 in 1918.[70] As illustrated in Table 1, 34,167 Fordsons were sold in its first year of domestic production. Agriculture was in a depressed state in the year 1921 and Ford reduced the price of the Fordson from $790.00 to $625.00, a price "below the cost of producing it, in an effort to expand output, lower per unit costs, and earn long-term profitability."[71] A year later, tractor inventories still increased and Fordson prices were reduced from $625.00 to $395.00,

which was followed by Ford's major competitor reducing the cheapest International Harvester model from $900.00 to $670.00.[72] Ford still dominated the industry. This is illustrated in th fact that Ford's share of the market increased from 25% in 1915, in its first year of production, to 75% in 1925; following the year 1925, Fordson production began to decrease and production was discontinued in the United States in 1928.[73]

TABLE 1

NUMBER OF FORDSONS SOLD COMPARED TO TOTAL

NUMBER OF TRACTORS SOLD

Year	Fordson Tractor Sales in U. S.	All Tractors Sold for Use in U. S.
1918	37,167	96,470
1919	56,987	136,162
1920	67,329[a]	162,988
1921	35,338[a]	-
1922	66,752[a]	100,092
1923	101,898[a]	115,040
1924	83,010[a]	96,639
1925	104,168[a]	118,739
1926	86,101[a]	122,940
1927	93,972	155,843
1928	8,001	99,820

ADAPTED FROM: Fordson Tractors Sold--Allen Nevins and Frank Ernest Hill, Ford: Expansion and Challenge 1915-1933 (New York: Charles Scribner's Sons, 1957), p. 685; Total tractors sold, 1916-1928--Agricultural Statistics 1940 (Washington, D.C.: U.S. Government Printing Office, 1940), p. 500; Total tractors sold, 1929-1950--Agricultural Statistics 1951 (Washington, D.C.: U.S. Government Printing Office, 1951), p. 537.

[a] Some of these tractors were sold to the Soviet Union.

Henry Ford produced the Model T at a price affordable to the general public and he also produced the Fordson at a price affordable to the average farmer. Henry Ford brought large-scale production to the tractor industry along with marketing and repair outlets. He changed the tractor industry from very small-scaled factories and manufacturing plants to large-scaled factories using the latest mass production techniques. Henry Ford dominated the tractor industry for a decade because of the technique of mass production. Many small tractor manufacturers merged together to meet this competition as the industry developed.

The supply of skilled labor and materials for production could have affected the rate of diffusion of the tractor. A shortage of skilled labor or needed material for the production of the tractor did not seem to slow the rate of diffusion. In fact, several times during the development of the tractor, manufacturers overestimated demand for tractors and oversupplied the market. Wik states that because of the overproduction of large tractors that were not adapted to the real needs of the farmer in 1912, the tractor industry suffered an almost total collapse.[74] Another time the tractor industry overestimated demand was in the early 1920's. Williams notes the result of this lack of demand. "Faced with falling demand, Ford's approach to maintaining his very high volume of production was to slash his prices. The policy, which put the ex-works price of a Fordson below production cost, meant a loss of a million

dollars."[75] There was a further lack of demand for tractors in the Great Depression. American industry in the period of the tractor's development was already involved with the needed material and labor to manufacture the tractor. This does not account for the slow diffusion of the tractor.

The supply conditions suggests that some of those supply factors increased the diffusion rate of the tractor. Innovations in the design of the tractor, greater efficiencies in the production processes, and economies of scale in the production of the tractor made the tractor both more useful and less expensive to the farmer.

Demand Conditions

Value of Land, Wage Rates, and Size of Farm

The study of the relevant demand conditions for the tractor is necessary for a full understanding of the diffusion rate of the tractor. Changing demand conditions can either increase or decrease the diffusion rate of a production technique. Three variables immediately stand out as possible factors affecting the diffusion rate of the tractor. These are the value of land and buildings per farm,[76] the size of the farms[77] and farm wages.[78] The diffusion rate of tractors should be affected by these demand conditions. This hypothesis is tested by use of a series of empirical tests for the years from 1920 to 1950.[79] These studies use tractors per farm as the dependent variable and use the value of land per farm,

the size of the farm, and farm wage rates as the independent variables. The data used for this study was obtained from censuses from 1920 to 1950. The values for the independent variables and dependent variable are from the 48 states. The data from each state is used as one observation.

Correlation coefficients are calculated for the years 1920, 1925, 1930, 1935, 1940, 1945, and 1950 in the first part of the study. The results of these studies are shown in Table 2.[80] The results of the correlation coefficients show that the variables in every year are highly correlated.

In the year 1920, the correlation coefficient between farm wage rates and tractors per farm was .78. Farm wage rates were positively correlated with tractors per farm in 1925, 1930, 1935, 1940, 1945 and 1950, with correlation coefficients of .62, .58, .40, .45, .69 and .76 respectively. It is hypothesized that this is because farming with tractors is more capital intensive than farming with horses (mules). As the wage rates for farm help increase, it becomes more economical to farm with the tractor. The correlation coefficients between farm wage rates and tractors per farm was .78 in 1920, dropped to .40 in 1935 and then increased to .76 in 1950. The explanation for this trend seems to be the sudden drop in wages that occurred in the Great Depression. With wage rates lower than they had been in many decades, farm wage rates were less significant in determining the type of power to use on the farm. As a whole, it appears that wage rates are correlated significantly

TABLE 2

CORRELATION COEFFICIENTS BETWEEN TRACTORS PER FARM, VALUE OF FARM, FARM WAGE RATES, AND SIZE OF FARM

(N=48)

Variables	Tractors per Farm	Value of Farm	Farm Wage Rates	Size of Farm
	1920			
Tractors per Farm	1.00			
Value of Farm	.84	1.00		
Farm Wage Rates	.78	.73	1.00	
Size of Farm	.84	.73	.71	1.00
	1925			
Tractors per Farm	1.00			
Value of Farm	.81	1.00		
Farm Wage Rates	.62	.55	1.00	
Size of Farm	.66	.62	.38	1.00
	1930			
Tractors per Farm	1.00			
Value of Farm	.73	1.00		
Farm Wage Rates	.58	.67	1.00	
Size of Farm	.74	.53	.31	1.00

TABLE 2--Continued

Variables	Tractors per Farm	Value of Farm	Farm Wage Rates	Size of Farm
		1935		
Tractors per Farm	1.00			
Value of Farm	.71	1.00		
Farm Wage Rates	.40	.69	1.00	
Size of Farm	.79	.49	.17[a]	1.00
		1940		
Tractors per Farm	1.00			
Value of Farm	.68	1.00		
Farm Wage Rates	.45	.59	1.00	
Size of Farm	.70	.39	.11	1.00
		1945		
Tractors per Farm	1.00			
Value of Farm	.64	1.00		
Farm Wage Rates	.69	.66	1.00	
Size of Farm	.75	.46	.51	1.00
		1950		
Tractors per Farm	1.00			
Value of Farm	.68	1.00		
Farm Wage Rates	.76	.61	1.00	
Size of Farm	.78	.50	.47	1.00

[a]Not Significant at .05.

with tractors per farm and needs further study to determine the effect it had on the diffusion rate of the tractor.

The value of land and buildings per farm is similarly highly correlated with tractors per farm. This variable had a positive correlation in 1920, 1925, 1930, 1935, 1940, 1945 and 1950, with the correlation coefficients of .84, .81, .73, .71, .68, .64 and .68 respectively. The most probable explanation for this correlation is that the higher the value of the farm the more likely the farmer would be able to purchase a tractor. Other reasons are the fact that farming with the tractor is somewhat more efficient in soil preparation and is also considerably faster than farming with horses (mules). The more valuable the farm, the more likely these matters would be taken into consideration. A farmer with a high stake in his farm would have an incentive to protect that investment. A farmer owning a valuable farm would have both the reasons and the capability of purchasing a tractor.

The third variable that has a high positive correlation to the number of tractors per farm is the size of the farm. The size of the farm in this study is the summation of cropland harvested and that of cropland that was not harvested and not pastured. This total should give a good approximation of the number of acres per farm that are in need of soil preparation. This is the type of land that the tractor or horses and mules would do the majority of work on. There is a positive correlation between the size of the farm and the number of tractors per farm. In 1920, 1925, 1930, 1935, 1940, 1945 and 1950 the

correlation coefficients were .84, .66, .74, .79, .70, .75 and .78 respectively. In each year, these variables are highly correlated. The rationale for this relationship is that there are economies of scale in farming with the tractor. Where there are only a few acres of land to prepare, there is little incentive to purchase a tractor that has the potential to plow many times that area of land.

The second part of the empirical study employs a regression analysis for examination of the relationship between the independent and dependent variables. Regressions were run on these variables for the years 1920 to 1950. The results are shown in Table 3. Regression coefficients were found for value of the farm, farm wage rates, and size of the farm. These independent variables explained much fo the variance in tractors per farm. The R^2 in the years 1920, 1925, 1930, 1935, 1940, 1945 and 1950 were .83, .74, .73, .76, .70, .72 and .83 respectively.

To illustrate the importance of these independent variables, values were inserted into the regression equations. This will help in determining the importance of one independent variable compared to the others. These results are shown in Table 4. Two sets of values were used for each independent variable. These values represent the approximate range of these variables in each particular year. In the year 1920, values of most farms ranged from $2,000 to $35,000 per farm. The affect that this variable had on a number of tractors per

TABLE 3

REGRESSION COEFFICIENTS AND STATISTICS OF FIT

FOR DEPENDENT VARIABLE TRACTORS PER FARM

(N=48)

Year	Intercept	Value of Farm	Farm Wage Rates	Size of Farm	R^2/F
1920	- .03394356 (-2.83873)	.00000215 (4.07460)	.0085091 (2.03066)	.00033440 (4.17225)	.83 73.98
1925	- .04275599 (-2.25474)	.00000594 (4.73076)	.02073712 (2.61394)	.00028632 (2.544.2)	.74 41.03
1930	- .06137206 (-1.77133)	.00000745 (2.64370)	.03482543 (2.02644)	.00099026 (5.46229)	.73 39.45
1935	- .02278412 (-0.76058)	.00001531 (3.50912)	.00366442 (0.15822)	.00118751 (6.69338)	.76 46.77
1940	- .05979342 (-1.30812)	.00002125 (3.23453)	.05286301 (1.69456)	.00159637 (5.99045)	.70 34.98
1945	- .06112526 (-0.76539)	.00001168 (2.11681)	.05090318 (2.45125)	.00188441 (5.36573)	.72 37.73
1950	- .15799125 (-1.70394)	.00000653 (2.22925)	.09822332 (5.07736)	.00198690 (6.54660)	.83 69.53

TABLE 4

ACTUAL VALUES FOR INDEPENDENT VARIABLES INSERTED INTO REGRESSION EQUATION TO SHOW EFFECT ON TRACTORS PER FARM

Year	Value of Farm (dollars)	Regression Coefficient X Value of Farm	Farm Wage Rates (dollars)	Regression Coefficient X Farm Wage Rates	Size of Farm (acres)	Regression Coefficient X Size of Farm
1920						
low	2,000	(.004)	2.10	(.018)	15	(.005)
high	35,000	(.074)	5.70	(.049)	275	(.092)
1925						
low	1,700	(.010)	1.30	(.027)	20	(.006)
high	25,000	(.148)	3.70	(.077)	300	(.089)
1930						
low	1,800	(.013)	1.10	(.038)	20	(.020)
high	25,000	(.185)	3.60	(.125)	320	(.317)
1935						
low	1,200	(.018)	.70	(.003)	15	(.018)
high	15,000	(.230)	3.00	(.011)	300	(.356)
1940						
low	1,600	(.034)	.80	(.042)	15	(.024)
high	16,000	(.339)	3.00	(.159)	320	(.511)
1945						
low	2,500	(.029)	2.20	(.112)	15	(.024)
high	25,000	(.290)	8.40	(.428)	350	(.660)
1950						
low	4,500	(.029)	3.00	(.295)	20	(.040)
high	45,000	(.293)	8.40	(.825)	400	(.795)

farm would thus range from .004 to .074. The affect of farm wage rates between $2.10 and $5.70 per day would be .0178 to .0485. The size of farms generally ranged from 15 to 275 acres of cropland per farm in 1920. This would cause tractors per farm to range from .005 to .092. The size of farms appeared to be the most important variable determing the number of tractors per farm during the years from 1920 to 1945. The value of the farm was the next most important variable during the years 1920 to 1940. During the years 1945 and 1950, the farm wage rate became a more important factor influencing the number of tractors per farm.

Statistics gathered from the 1950 census on the farms reporting tractor use further illustrate that both the size of the farm[81] and the economic class of the farm[82] significantly affect the number of tractors used on the farm. These data were based upon a sample of farms for the census of 1950. This study is based upon individual farms and not farm statistics from each of the 48 states. The farm is the unit of observation. The data of this study is not completely compatible with the data of the previous study. The economic class of the farm in this study is based upon the value of all farm products sold, while the data from the previous study was the value of the land and building per farm. While these variables are not the same, the two variables should be highly correlated with one another. The size of the farm in this study is also calculated differently. In the previous study, the size of the farm was

calculated by adding together the amount of cropland harvested and the amount of cropland not harvested and not pastured. The size of the farm in this study includes all the land in the farm. A third difference between this study and the former study is the fact that this study measures the percentage of farms reporting tractors instead of the average number of tractors per farm. While this study is not completely comparable to the previous study, it does offer the opportunity to re-examine the correlation between both the size of the farms versus the number of tractors and the value of farms versus the number of tractors. The results of this analysis are presented in Figures 4 and 5.

The results of Figure 4 show that the size of the farm has a positive correlation with the percentage of farms reporting tractors. As the farm increased from under 10 acres in size to between 140 to 179 acres in size, the percentage of farms reporting tractors increased from 15.2% to 70.2%. The results further show that, as the size of the farm increased from 140 to 179 acres to 500 to 999 acres, the percentage of farms reporting tractors increased from 70.2% to 84.9%. For farms that were over 1,000 acres, the percentage of farms reporting tractors actually declined slightly from 84.9% to 82.0%. This clearly reasserts the relationship found between the size of the farm and the number of tractors on those farms in the previous study.

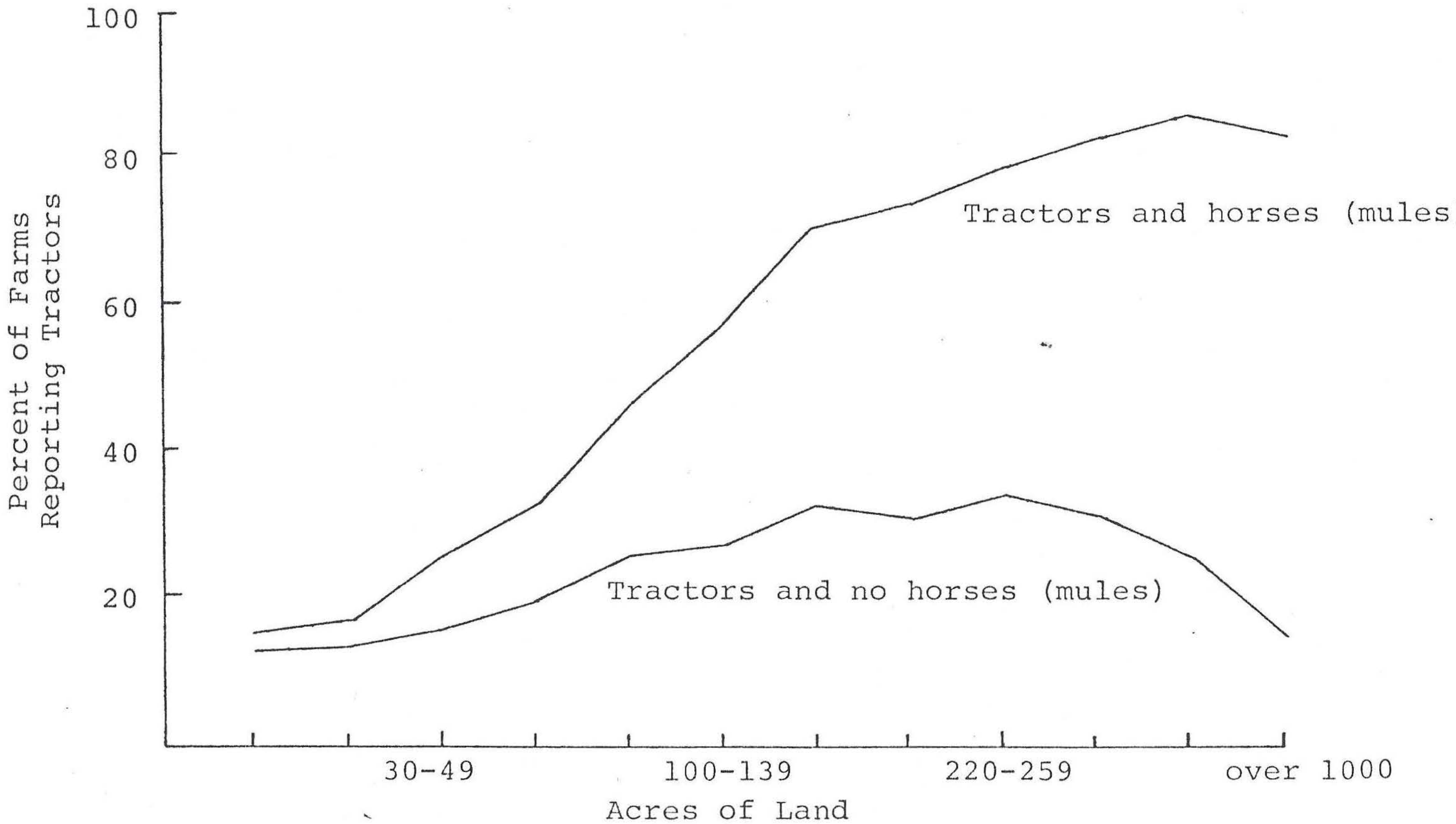

Fig. 4.-- Percentage of farms reporting tractors in relationship to the size of the farm. ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, <u>1950 Census of Agriculture</u>, vol. 2, <u>General Report</u>, pp. 788-89.

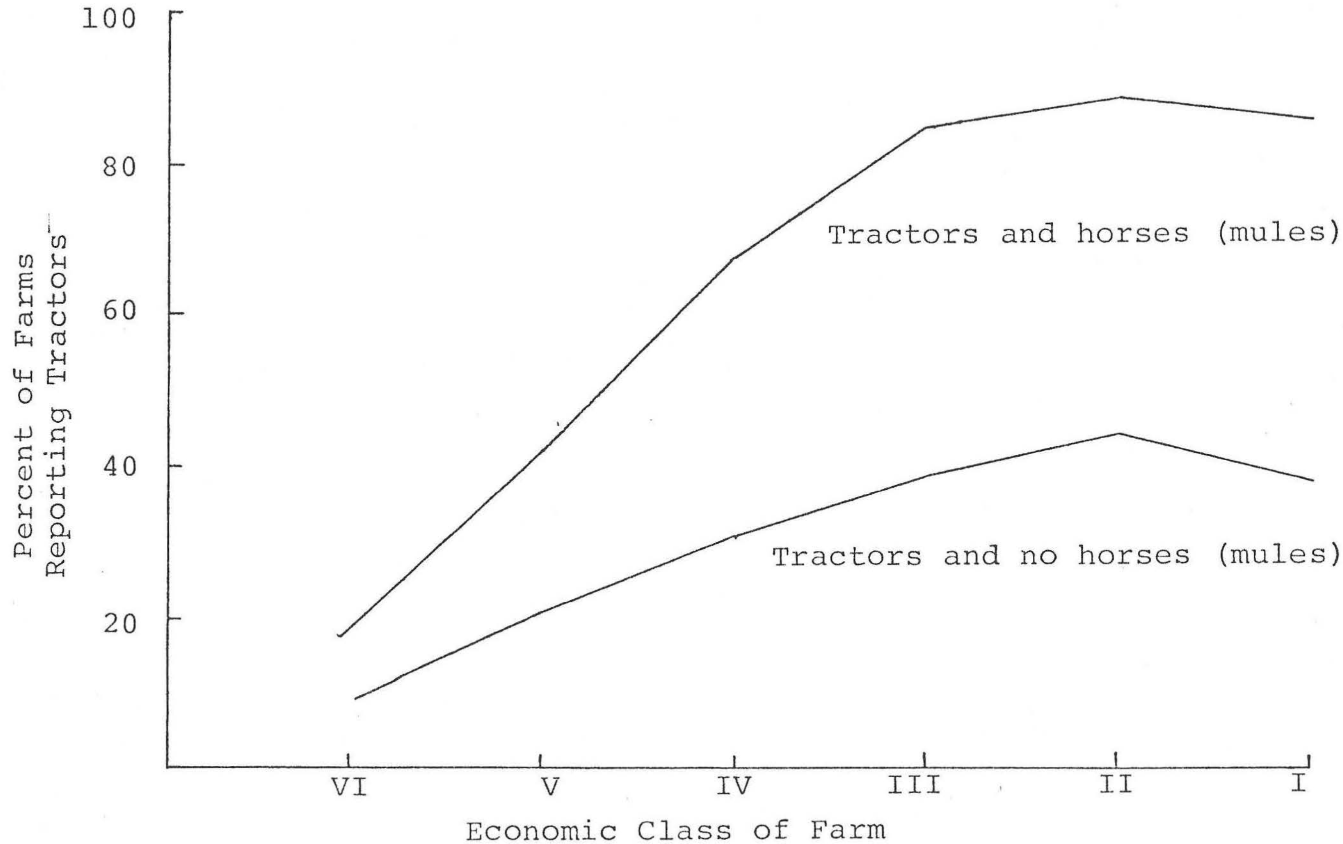

Fig. 5.--Percentage of farms reporting tractors in relationship to the economic class of the farm. ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, 1950 Census of Agriculture, pp. 1122-23.

The results of Figure 5 indicate that the economic class of the farm has a positive correlation with the percentage of farms reporting tractors. As the economic class of the farm increased from Class VI to Class III, the percentage of farms reporting tractors rose from 29.4% to 85.8%. From Class III to Class II, farms reporting tractors increased only slightly from 85.8% to 89.1%. When the economic class of the farm increased from Class II to Class I, the percentage of farms reporting tractors declined from 89.1% to 86.1%.

These two studies provide substantial evidence that the economic class of a farm, the size of a farm and the farm wage rates have a high positive correlation to the number of tractors on the farm. Each of these demand conditions may have had an effect upon the diffusion rate of the tractor in the period between 1920 and 1950. If these demand conditions changed significantly over that period of time, the diffusion rate of the tractor may have changed in response to those changes in demand conditions. An examination of changes in these demand conditions from 1920 to 1950 is necessary to determine their effect upon the diffusion rate of the tractor.

If these demand conditions affected the diffusion rate of the tractor, it would be expected that their movements over time would correspond to the movements of the number of tractors per farm over time. In an attempt to evaluate the relationship between the demand conditions and the diffusion rate of the tractor, the value of the farm,[83] the farm wage

rates,[84] the size of farms[85] and the number of tractors per farm[86] are compared during the period from 1920 to 1950. This data is for the United States as a whole.[87]

The results show that the number of tractors per farm increased from 1910 to 1950 as shown in Figure 6. During those years, the number of tractors increased slowly in the period from 1910 to 1918. During those years, the number of tractors increased only from .00016 per farm to .013 per farm. From 1918 to 1930, the number of tractors per farm increased more rapidly from .013 to .141. The number of tractors per farm throughout the Great Depression stayed relatively constant. They increased from .141 to .167 in that time period. The period from 1936 to 1950 produced the most rapid increase of tractors on the farm. They increased from .167, in 1936, to .601 in 1950.

The value of the farm steadily increased from 1910 to 1920, where the value increased from $5,431 to $10,173. The value of the farm decreased from $10,173 to a low of $4,569 in 1933. It increased again from that point until it reached its maximum of $13,391 in 1949. The comparison between the value of the farm and the number of tractors per farm is illustrated in Figure 6. During the years from 1910 to 1918, the number of tractors stayed relatively constant, while the value of the farm increased. The number of tractors per farm reached its first turning point in 1917-18, when they began to increase more rapidly. Both variables reached an early

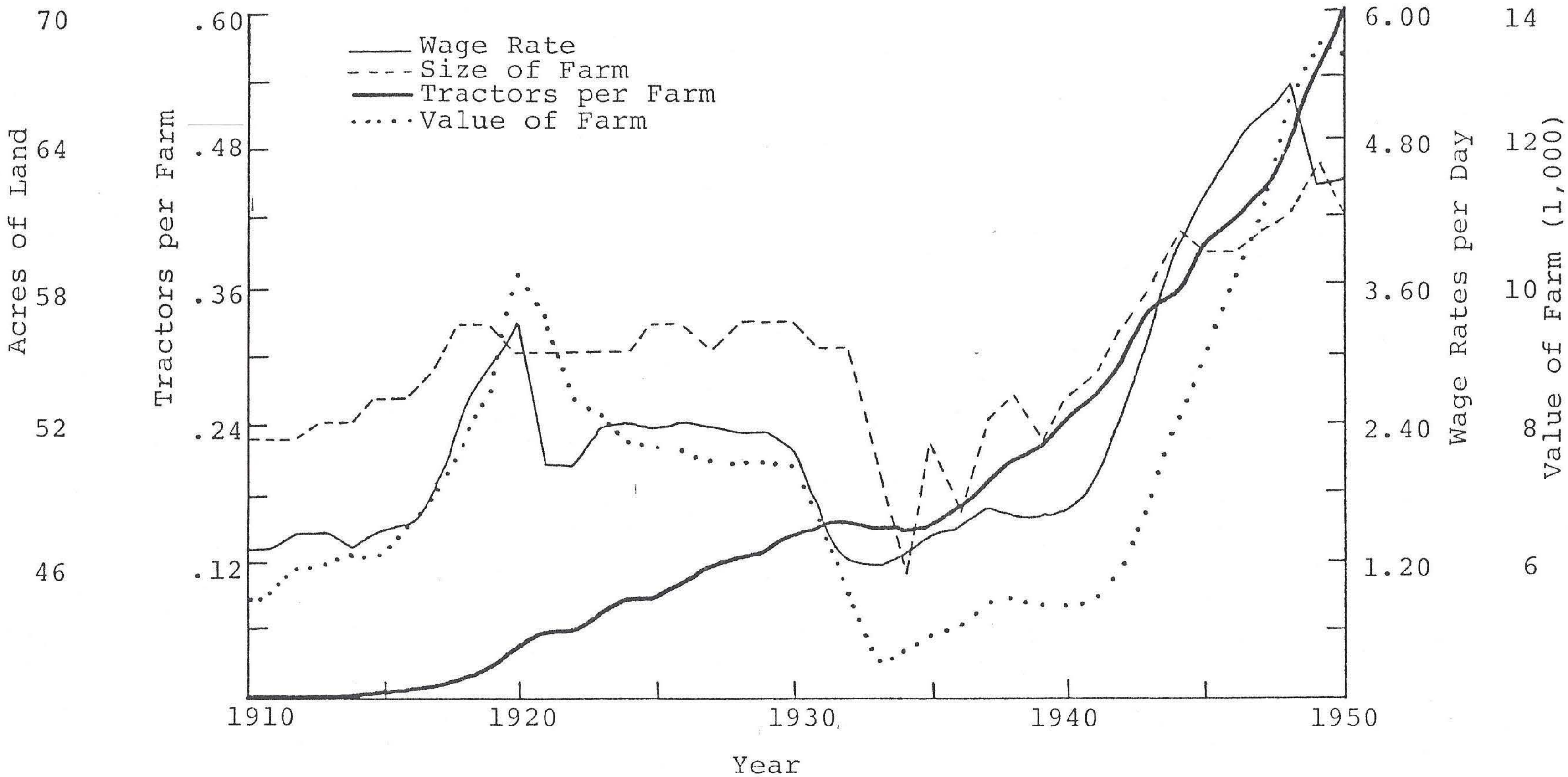

Fig. 6.--Tractors per farm compared to value of the farm, size of the farm, and farm wage rates, 1910-1950. ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States, pp. 278, 280, 281, 285.

peak during the early twenties. For approximately the next decade after 1921, the trends were in opposing directions. The value of the farm declined and the number of tractors per farm continued to increase. During the years of the Depression, the number of tractors per farm reached its second turning point. The number of tractors per farm stayed relatively constant, while the value of the farms dropped slowly. The years of recovery from the Depression caused both the value of the farm and the number of tractors per farm to increase suddenly. Both increased at a rapid rate until 1950. It is probable that the value of the farm had an impact on the number of tractors per farm. The value of the farm fluctuated greatly during this time period. The value ranged from a low of $4,596 to a high of $13,391. It has already been shown that the value of the farm has a high positive correlation to the number of tractors per farm. It is highly probable that the fluctuations of the value of the farm both increased and decreased the rate of diffusion of the tractor. It is also evident from this study that the value of the farm is not the overriding determining factor of the diffusion rate of the tractor. The fact is that the value of the farm decreased during the mid-twenties to the early thirties, while the number of tractors increased during that same period. It leads to the conclusion that the value of the farm was a contributing factor in the diffusion rate of the tractor but that other factors were still more important during at least part of the period.

The size of the farm fluctuated proportionally less than the value of the farm. The acres of harvested crops increased from 51 in 1910 to 56 in 1930. It decreased from 56 acres in 1930 to 45 acres in 1933. During the period from 1933 to 1950, the acres of harvested crops increased from 45 acres in 1933 to 63 acres in 1949. This trend is similar to the trend of the value of the farm. The big difference is that the size of the farm or acres of harvested crops varied little during the whole period of time. This is illustrated by Figure 6. This change would amount to an increase of barely one classification of the size of farms as presented in Figure 5. It is likely that this change in the size of the farm measured by the acres of harvested cropland is insignificant in determining the causes of the changes in the diffusion rate of the tractor.

The value of the farm wages followed a similar pattern as the value of the farm from 1910 to 1950. Farm wages averaged $1.35 per day without board in 1910 and rose to $3.30 in 1920. From $3.30 in 1920, farm wage rates decreased to a minimum level of $1.15 in 1933. Farm wage rates began to slowly rise in the later years of the depression and sharply increase in the 1940's to a high of $5.10 in 1948. As in the case with the value of the farm, farm wage rates seem to have had an impact upon the number of tractors per farm. The large increase of wage rates during the years from 1917 to 1920, provided incentive for the farmer to adopt farming techniques that were more capital intensive. This corresponds with the

first turning point in the number of tractors per farm. The time period from the early twenties to the early thirties, showed that farm wage rates were decreasing while the number of tractors per farm were increasing. Wages also decreased rapidly during the worse years of the Great Depression, while the number of tractors stayed relatively constant. This trend of farm wage rates did not offset other factors contributing to an increase in the number of tractors per farm. With farm wage rates increasing nearly five times from 1933 to 1948, it is highly probable that this had a positive influence upon the rapid increase of the tractors per farm during that period. The conclusion to be reached seems to be that the increasing farm wage rate did provide a stimulus to the number of tractors per farm. It is also likely that decreasing wage rates did depress the demand for more tractors but not enough to offset the other factors causing an increase in the number of tractors per farm.

Other Demand Conditions

The value of the farm, size of the farm and farm wage rates are all important demand conditions that warranted special attention. The value of the farm would be included under an individual aspect of demand. This variable is basically a wealth measurement. The size of the farm measured possible economies of scale. Farm wage rates is a factor price of both types of farming. There are other demand conditions that also must be examined. One of these is other factor prices. These

include the price of gasoline, the price of feed and the price of other miscellaneous goods. Another factor deserving attention is the supply of labor and materials to operate the two techniques. Changes in these demand conditions during the years from 1910 to 1950 could have affected the diffusion rate of the tractor.

The price of gasoline and other petroleum products is a major factor in the cost of operating a tractor. It is conceivable that changes in the price of gasoline could have affected the diffusion rate of the tractor. Increases in the price of gasoline would lead to higher costs in the operation of the tractor, while decreases in the price of gasoline would lead to lower costs. An index of gasoline prices for the year 1913 and the years 1923 to 1950 are shown in Figure 7. The index for gasoline prices starts at a high of 343 in 1913 to a low of 96 in 1940. From 1940 to 1950, gasoline prices rapidly increase to 298.[88]

The price of feed is the primary cost involved in th operation of the horse (mule). As the price of feed increased, it is probable that farmers would switch to a technique of farming that did not use feed. As the price of feed decreased, it is possible that the farmer would be hesitant to adopt a new technique of farming because of the decreasing costs of farming with the horse. Figure 7 shows the price index of crops from the years 1910 to 1950. The prices received for crops should be a fair approximation of the price of feed over those years. The index of prices received by the farmer for their

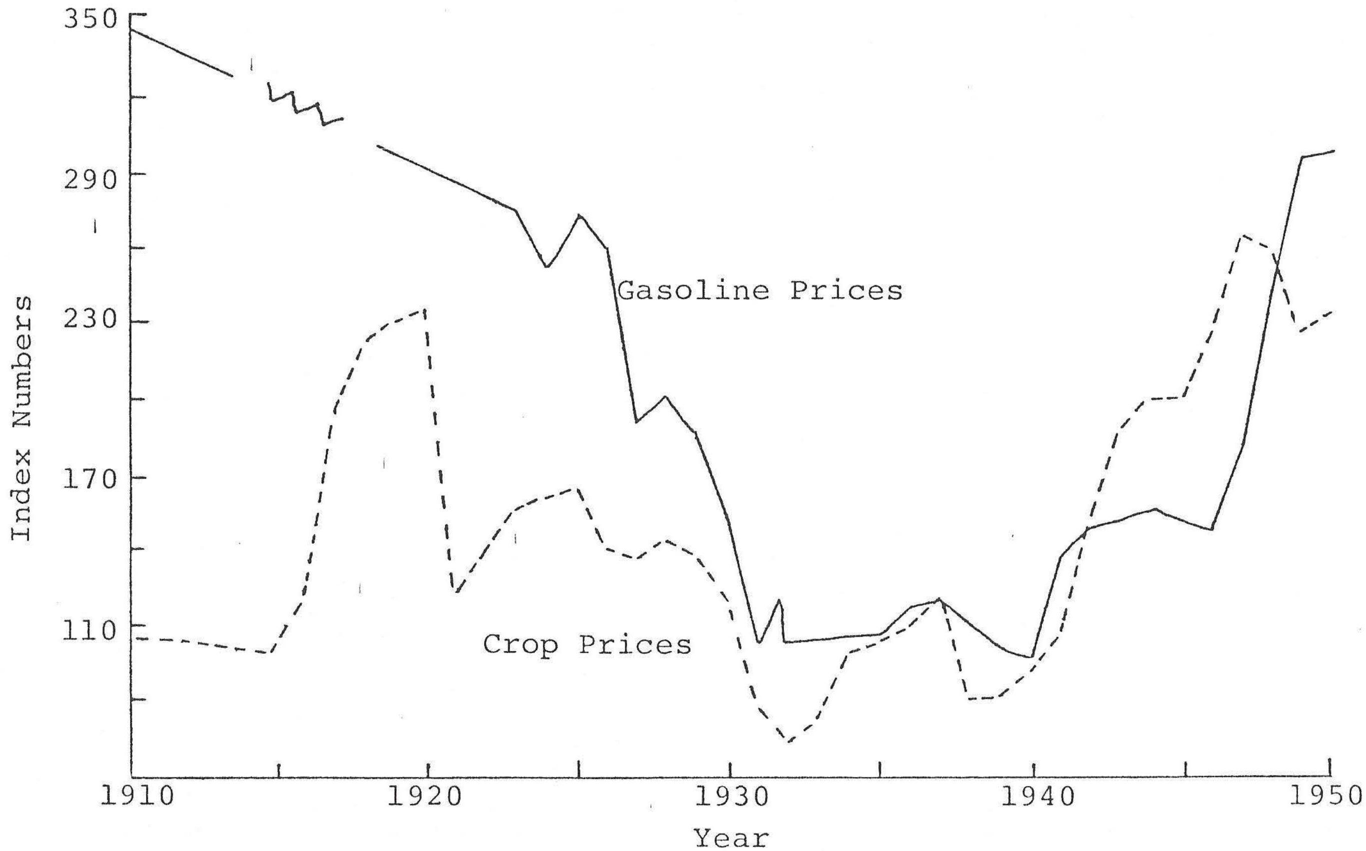

Fig. 7--Index of gasoline and crop prices. ADAPTED FROM: Gasoline prices--U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States 1923 (Washington, D.C.: U. S. Government Printing Office, 1923, p. 314; Statistical Abstract 1928, p. 322; Statistical Abstract 1933, p. 283; Statistical Abstract 1937, p. 343; Statistical Abstract 1941, p. 358; Statistical Abstract 1951, p. 280; Statistical Abstract 1952, p. 275; Crop prices--U.S. Department of Commerce, Bureau of Census, Historical Statistics of the United States, p. 283.

crops fluctuated considerably during the years from 1910 to 1950. The index varied from 105 in 1910 to an early peak of 235 in 1920. After taking a sharp plunge in 1921 to 121, the index generally declined until it reached a minimum of 57 in 1932. The index increased from that low point in 1932 to a high of 163 in 1947.[89]

Not only could the price of factors have an influence upon the diffusion rate of the tractors, but the supply of labor and materials also could have affected the diffusion rate. One factor that seems important in the early years of the tractor development is World War I. During those years, labor as well as horses were scarce. Again, in World War II, labor was scarce on the farm. The demand for tractors increased because of these factors. While the price of gasoline was declining during the early years of the tractor use, it is also true that the supply of gasoline was scarce until the use of the automobile became widely diffused. In most cases, the scarcity of the supply was shown in higher prices.

The examination of demand conditions has shown that several of these variables could have affected the diffusion rate of the tractor. The value of land and buildings and the farm wage rate have positive correlation with the number of tractors per farm. These two variables also seem to explain some of the diffusion of the tractor from 1910 to 1950. The size of the farm did not change enough during the years 1910 to 1950 to significantly affect the rate of diffusion of the

tractor. The price of gasoline did change during this period. It could have affected the number of tractors on the farms. The price of feed fluctuated during this period. It is also interesting to note that the price index for crops is very similar to that of the value of the farm with possibly a year or two lag. Both these variables have a positive correlation to the number of tractors on the farm. It is nearly impossible to differentiate the affect of one from the other. The supply of labor and material also is a factor that must be considered. The shortage of labor certainly acted as a stimulus to the diffusion rate of tractors.

Usefulness of Animal Power and Tractor Power

Horses (mules) and tractors provided the majority of the power for the operation of farms in the twentieth century. The farmer needed to examine the usefulness of these techniques of supplying power. The usefulness of the horse did not change significantly during this period. Most of the significant improvements in horse drawn implements occurred during the nineteenth century. The improvements in horse drawn equipment were small in comparison to the advancements in tractors and tractor implements. The improvement of the tractor during the twentieth century was examined earlier in the paper. It was shown that the tractor became more useful and efficient. The tractor of 1900 could do only a fraction of the things that a tractor in 1950 could do. There were also a vast number of improvements in the implements used with the tractor. The following is a statement on the effectiveness of the tractor in 1940:

> The tractor brings more drawbar power to particular operations, and thus makes it possible to use larger and more effective equipment at a higher speed than is feasible with horses. Belt pulleys on tractors provide mobile power for work otherwise done with a stationary engine. The power take-off, a substitute for the belt pulley in some work, increases the efficiency and dependability of harvesting equipment like mowers, binders, small combined harvester-threshers, corn pickers, and field silage cutters.
>
> From the heavy,cumbersome tractor, limited to draft work and certain belt operations, the trend has been to lighter, high-speed tractors adapted to various uses.[90]

The implements designed for use with the horse are restricted because of the limitations of the horse. The horse can only provide a limited amount of drawbar power and speed. It does not provide high speed pulley power and cannot provide a power take-off. The horse cannot supply power for hydraulic machinery. These place limits on the type of implements that can be designed for horse drawn equipment. The result has been a long list of improvements of tractors and tractor implements during the period from 1910 to 1950. There have been few corresponding improvements in horse drawn equipment during this same period.

It is difficult to compare the actual work done by the horse with that done by the tractor for this time period. The work done by horse power changed little and can be estimated. The problems arise when attempting to estimate the amount of work done by the tractor. The work done by the tractor in 1910 is not the same as the work done by the tractor in 1950. In fact, the work done by one type of tractor in any year is different from the work done by another brand of tractor in that same year. There is no easy way to remedy this problem.

A direct comparison between the amount of work done by the horse versus the tractor would help illustrate the usefulness of each technique to provide power to the farmer. Because of the problems mentioned above, any comparison for one year cannot tell the whole story, but can give some insight into the farmer's decision whether to farm with horses, tractors or a combination of the two. Table 5 illustrates the results from a study completed in 1929 showing the time required for horses to perform several tasks.[91] The tractor was found to do five out of six of these operations in less time than the horses. Cultivating corn was the only operation that was done faster with the horses than with the tractor. The tractor has the largest advantage over the horses in harrowing, where it took the tractor only .28 of an hour for one acre while it took horses 1.03 hours for one acre. For these operations, it is apparent that the tractor could work at a faster rate than the horses. This is one advantage of the tractor over horses. These are, however, only a small number of operations that must be performed on the farm. The early tractor could not perform all of these operations. As the tractor developed, it could perform more of these tasks. By the 1940's and 1950's, the tractor became versatile enough to do most of the necessary operations on the farm previously done by the horse. The tractor developed from machinery whose primary function was soil preparation to a machine that could do nearly all the jobs on the farm where power was necessary. A list of farm operations

TABLE 5

COMPARISON BETWEEN HORSES AND TRACTORS IN

PERFORMING SEVERAL FARM TASKS

Farm Tasks	Size Machine	Acres Covered	Hours per Acre
PLOWING			
Horses (4)	26 in.	126	2.02
Tractor	26 in.	91	1.22
DISKING			
Horses (4)	9 ft.	7,932	.49
Tractor	9 ft.	294	.29
HARROWING			
Horses (4)	18 ft.	2,803	1.03
Tractor	18 ft.	92	.28
PLANTING CORN			
Horses (2)	2-row	2,804	.69
Tractor	2-row	197	.36
CULTIVATING CORN			
Horses (4)	2-row	1,697	.59
Tractor	2-row	458	.74
CUTTING SMALL GRAIN			
Horses (4)	8 ft.	1,241	.86
Tractor	8 ft.	232	.60

ADAPTED FROM: John A. Hopkins, Jr., Horses, Tractors and Farm Equipment, pp. 393-98.

divided into tractor operations, doubtful tractor operations and non-tractor operations illustrates the many tasks that power was necessary for the farm. They are classified by the most economical way to perform the operation in the year 1921:[92]

> Tractor Operations -- Plowing, Disking, Harrowing, Cutting stalks (with disk), Dragging (field), Pulling hedges, Rolling and harrowing corn (combined), Cultivating for oats, Disking and harrowing (combined), Working roads with grader, Harrowing stalks, Pulverizing with Tower Pulverizer, Rolling and harrowing (combined).
>
> Doubtful Tractor Operations -- Hauling gravel (more than one wagon, Rolling, Drilling wheat-oats-rye, Cutting corn with binder, Cutting small grain with binder, Cutting soybeans with binder, Cutting timothy with binder, Pulling hay loader, Other hay work, Hoisting, Hauling feed (more than one wagon), Hauling fertilizer (more than one wagon).
>
> Non-tractor Operations -- Cultivating corn, Mowing hay, Planting corn, Husking corn, Hauling manure, Plowing in gardens, truck patches, and around end of fields, Horse labor for household and personal use, Feeding livestock, Miscellaneous hauling about farm, Hauling small quantities of products to and from market, Working in garden, Working around farmstead, Cultivating soybeans, Seeding soybeans, Working in seed-corn plot, Threshing, Hauling, Raking hay, Tedding hay, Putting hay into barn or stack, Picking up corn after binder, Hulling clover, Hauling, Mowing weeks, Opening ditches along fence rows, Baling hay and straw, Hauling, Sowing grass seed, Gather seed corn, Hauling fodder, Cultivating corn with weeder, Raking stubble field, Building and repairing fences, Breaking stalks in winter, Cutting stalks with stalk cutter, Harrowing corn, Rolling corn, Drilling alfalfa, Rolling, Curing alfalfa, Filling silo, Hauling, Drilling small grain (one horse drill in standing corn).

With the passage of time, the tractor became capable of performing more and more of the tasks classified under non-tractor operations. But the important point is that the tractor was not a self-sufficient power source in the 1920's. The farmer had no choice but to keep horses on their farms.

While the horse could not plow as well, could not supply a power take-off, or move as fast, it was still a very versatile power source. For this reason, the tractor was thought to be complementary to the horse, not a substitute for the horse during much of the period. John Hopkins states in 1929 that ". . . horses and tractors should not be regarded as competing but as complementing each other."[93] The versatility of the horse was an important reason for the slow rate of diffusion of the tractor.

Cost of Horses Versus Cost of Tractors

The Need for Comparison

One of the major decisions of the farmer during this period was to determine whether the tractor or the horse was the more economical to use. If the farmer rationally attempted to maximize his earnings, then the farmer was involved in comparing the costs of one production technique versus the other production technique. The diffusion rate of the tractor should have been strongly affected by the relative cost of horse power and tractor power. An analysis of those comparative costs would give valuable insight into the diffusion rate of the tractor. An examination of these costs from 1910 to 1950 and the underlying causes for changes in these costs aids in the understanding of the relatively slow diffusion rate of the tractor.

Tractor Costs

An examination of the costs of tractor operations during this time period is a difficult undertaking. There are many variables that affect these costs of operation. One type of tractor does not cost the same to operate as another. One type of tractor does not perform the same as another and identical tractors do not perform equally in different environments. Tractors are less costly to operate on level ground than on hilly terrain. Tractors perform better on some types of crops than on other types of crops. The tractor is most efficient to operate on a farm that is neither too small or too large. Thus, the costs of operating a tractor will vary from one set of circumstances to another. These are problems inherent in studying the cost of operating the tractor on the farm. This does not mean that the costs of tractor operations cannot be estimated for specific situations. It only means that the comparative costs of tractor power and horse power vary in different circumstances.

Tractor costs from 1910 to 1950 were first estimated by using case studies of actual costs from different regions of the country. These studies were made primarily by regional Agricultural Experimental Stations and the United States Department of Agriculture. These studies seem to be unbiased towards the use of either the horse or the tractor. Use is not made of cost studies of tractors made by tractor companies because of the possibility of bias. The studies give as accurate a picture of the costs of tractor operations as there

is available. A summary of these studies is shown in Table 6. There are 20 case studies presented. Included in each study is the average costs of operating a tractor for a particular year. These costs were calculated from questionnaires completed by the farmers who used the tractors during this time period. The studies were used to give the farmer accurate information on the costs of tractor operation. The costs of tractor operations are broken into six classifications. These are depreciation, repairs/maintenance, interest, lubrication, fuel and miscellaneous costs. Also listed under each study is other information pertaining to the use of the tractor. These include the average size of crops planted, average cost of the tractor, average size of the tractor, hours of tractor use per year, estimated life of the tractor, age of the tractor, and the percentage of custom work. These figures show under what conditions the tractor costs were calculated. These cost figures are taken from various parts of the country and are not completely comparable. These studies do give a good approximation of tractor costs from 1914 to 1939. The additional information of the average size of crops planted, average cost of the tractor, average size of tractor, hours of tractor use per year, estimated life of the tractor, age of the tractor and percentage of custom work help in making the studies more comparable. Case studies 1 and 4 in Table 6 serve to illustrate some of the problems involved in directly comparing the studies. The total cost of operating a tractor per year in case study 1 is $1,372 and in case study 4 is $495.00.

TABLE 6

CASE STUDIES SHOWING COST AND MISCELLANEOUS DATA

FOR TRACTOR USAGE REPORTED BY FARMERS

Tractor Data	1914 (1)	1917 (2)	1917 (3)	1919 (4)	1919 (5)
Depreciation	396.00	98.00[a]	140.00[a]	269.10	168.00
Repairs/Maintenance	80.00[a]	33.00[a]	41.00[a]	33.70	124.00
Interest	89.00[a]	25.00[a]	31.00[a]	39.72	47.00
Lubrication	124.00[a]	31.00[a]	29.00[a]	28.85	29.00
Fuel	683.00[a]	130.00[a]	141.00[a]	119.44	84.00
Miscellaneous				4.83	20.00
Total Cost/Year	1,372.00	317.00	382.00	495.64	372.00
Cost per Hour	1.25	.58	.85	.98	1.19
Fuel/Lubrication (400 Hours)	249.00	119.00	151.00	117.00	144.00
Total Cost (400 Hours)	859.00	275.00	363.00	464.00	403.00
Av. Size Crops	. . .	. . .	. . .	123	94.4
Av. Cost Tractor	2,537.00	830.00	1,055.00	959.00	. . .
Av. Size Tractor	. . .	2.2	2.6	2.6	. . .
Hours in Use	1,099	540	450	506	313
Life of Tractor	6.4	8.5	7.5	8.1	. . .
Age of Tractor	2.1	. . .	. . .	1.5	. . .
% Custom Work		18%	18%	18%	20%

TABLE 6--Continued

Tractor Data	1919 (6)	1919 (7)	1920 (8)	1921 (9)	1921 (10)
Depreciation	187.25	160.00	154.00	216.61	199.16
Repairs/Maintenance	83.19	74.00	49.00	71.00	76.60
Interest	39.72	38.00	31.00	62.39[a]	61.28
Lubrication	37.57	27.00	27.00	49.67[a]	65.11
Fuel	137.38	78.00	78.00	160.60[a]	248.95
Miscellaneous	8.25	18.00	18.00	. . .	. . .
Total Cost/Year	493.37	395.00	357.00	357.00	560.27
Cost per Hour	1.16	1.40	1.27	1.49	1.70
Fuel/Lubrication (400 Hours)	165.00	149.00	149.00	224.00	328.00
Total Cost (400 Hours)	483.00	439.00	401.00	574.00	665.00
Av. Size Crops	137.6	105.8	95.9	352.0	378.0
Av. Cost Tractor	992.00	. . .	. . .	1,473.00	1,820.00
Av. Size Tractor	2.2	. . .	. . .	2.9[a]	4.2
Hours in Use	425	282	281	376	383
Life of Tractor	6.0	. . .	. . .	6.8	10.5
Age of Tractor	2.2	. . .	. . .	. . .	4.8
% Custom Work	20%	15%	20%	. . .	29%

TABLE 6--Continued

Tractor Data	1922 (11)	1922 (12)	1923 (13)	1925-27 (14)	1926 (15)
Depreciation	134.00	157.00	154.00	83.87	97.20
Repairs/Maintenance	38.00	71.00	71.00	34.01	27.51
Interest	25.00	49.00	48.00	26.93	25.82
Lubrication	25.00	42.50[a]	40.00[a]	34.01	25.34
Fuel	73.00	135.00[a]	127.50[a]	81.56	88.39
Miscellaneous	18.00	. . .	. . .	. . .	4.37
Total Cost/Year	313.00	454.50	440.40	282.03	268.63
Cost per Hour	1.18	1.26	1.21	.93	.86
Fuel/Lubrication (400 Hours)	184.00	197.00	184.00	153.00	145.00
Total Cost (400 Hours)	399.00	474.00	457.00	201.00	300.00
Av. Size Crops	93.0	. . .	. . .	156	107.0
Av. Cost Tractor	. . .	1,065.00	1,045.00	. . .	745.00
Av. Size Tractor	. . .	. . .	. . .	. . .	2.1
Hours in Use	265	361[a]	364[a]	303	313
Life of Tractor	. . .	6.8	6.8	. . .	8.2
Age of Tractor	. . .	. . .	. . .	. . .	3.2
% Custom Work	15%	. . .	. . .	. . .	15%

TABLE 6--Continued

Tractor Data	1927-31 (16)	1930 (17)	1930 (18)	1934 (19)	1939 (20)
Depreciation	89.00	109.00	155.00	39.15	78.00
Repairs/Maintenance	36.00	40.00	50.00	25.65	18.00
Interest	28.00	47.00	92.00	19.43	36.00
Lubrication	120.00	36.00	233.00	13.21	12.00
Fuel		151.00		51.77	74.00
Miscellaneous	. . .	. . .	. . .	6.56	7.00
Total Cost/Year	273.00	383.00	530.00	155.77	225.00
Cost per Hour	.59	.87	.95	.66	.49
Fuel/Lubrication (400 Hours)	104.00	170.00	166.00	110.00	75.00
Total Cost (400 Hours)	257.00	347.00	463.00	201.00	214.00
Av. Size Crops	220	. . .	553	96	100
Av. Cost Tractor	. . .	1,079.00	. . .	. . .	. . .
Av. Size Tractor	2.2	2.5	3.0	2.2	1.7
Hours in Use	460	440	560	236	457
Life of Tractor	. . .	10.0	. . .	. . .	. . .
Age of Tractor	. . .	4.7	. . .	6.3	3.1
% Custon Work	. . .	. . .	5%	15%	2%

ADAPTED FROM: Column 1--Arnold P. Yerkes and H. H. Moury, Farm Experience with the Tractor, U.S.D.A. Bulletin 174, Washington, D.C., 1915, pp. 1-44; Column 2--Arnold P. Yerkes and L. M. Church, The Gas Tractor in Eastern Farming, U.S.D.A. Farmers'

TABLE 6--Continued

Bulletin 1004, Washington, D.C., 1918, pp. 1-27; Column 3--Arnold P. Yerkes and L. M. Church, Tractor Experience in Illinois: A Study of the Farm Tractor Under Corn-Belt Conditions, U.S.D.A. Farmers' Bulletin 963, Washington, D.C., 1918, pp. 1-29; Column 4--D. S. Fox, An Economic Study of the Gas Tractor in Pennsylvania, Penn. Agr. Exp. Sta. Bulletin 158, Centre County, 1919, pp. 1-20; Column 5--F. L. Morrison, The Tractor on Ohio Farms, Ohio Agr. Exp. Sta. Bulletin 383, Columbus, 1925, pp. 1-30; Column 6--U. I. Myers, An Economic Study of Farm Tractors in New York, N.Y. Agr. Exp. Sta. 405, Ithaca, 1921, pp. 53-134; Column 7--F. L. Morrison, pp. 1-30; Column 8--F. L. Morrison, pp. 1-30; Column 9--N. H. Trolley and W. Humphries, Tractors and Horses in the Winter Wheat Belt, Oklahoma, Kansas, Nebraska, U.S.D.A. Bulletin 1202, Washington, D.C., 1924, pp. 1-59; Column 10--H. E. Selby, The Gas Tractor in Montana, Mont. Agr. Exp. Sta. Bulletin 151, Bozeman, 1922, pp. 1-24; Column 11--F. L. Morrison, pp. 1-30; Column 12--N. H. Trolley and W. Humphries, pp. 1-59; Column 13--N. H. Trolley and W. Humphries, pp. 1-59; Column 14--John A. Hopkins, Jr., pp. 393-398; Column 15--C. W. Gilbert, An Economic Study of Tractors on New York Farms, N.Y. Agr. Exp. Sta. Bulletin 506, Ithaca, 1929, pp. 1-80; Column 16--P. E. Johnston and J. E. Wills, The Study of the Cost of Horse and Tractor Power on Illinois Farms, Ill. Agr. Exp. Sta. Bulletin 395, Urbana, 1933, pp. 266-332; Column 17--A. J. Schwentes and G. A. Ponds, The Farm Tractor in Minnesota, Minn. Agr. Exp. Sta. Bulletin 280, St. Paul, 1931, pp. 1-87; Column 18--C. M. Hampson and Paul Christophersen, Tractor and Horse Power, So. Dak. Agr. Exp. Sta. Circular 6, Brookings, 1932, pp. 1-39; Column 19--K. J. Wright, 1934 Tractor Costs in Michigan, Mich. Agr. Exp. Sta. The Quarterly Bulletin 18, East Lansing, 1935, pp. 49-53; Column 20--F. M. Atchley, Tractor Costs in Michigan, 1937, Mich. Agr. Exp. Sta. The Quarterly Bulletin 23, East Lansing, 1940, pp. 99-105.

[a]Estimated from data.

But the tractors in study 1 were operated for an average of 1,099 hours per year, while those in study 2 were operated for an average of only 506 hours per year. After adjusting for the differences in hours of use, the total costs per year are not nearly as far apart. The total cost of operating tractors for a period of 400 hours for the first study is $859.00 and for the other study is $464.00. This adjustment is made for all of the studies. Other differences are not adjusted. Tractor size varies from one study to another. A larger size tractor is obviously more expensive to operate per year but because of increased performance may be more efficient to operate per acre of land. Differences in the average size of the crops and differences in the type of crop can also affect the operation costs of the tractor per year. The age of the tractor is another possible reason for differences in the cost of tractor operations per year. When the set of circumstances for each study is taken into account, these studies should yield an accurate picture of the costs involved in operating a tractor.

A summary of these case studies is presented in Figure 8. This graph shows the total cost per year of operating a tractor. The cost of tractor operation for each study is figured on the basis of 400 hours of tractor operation per year. The dashed line is the summary of all the case studies. It is seen that the general trend of tractor costs is decreasing. but the decline is very uneven. Tractor costs peaked in the years 1914, 1921 and 1930. The primary cause for these relatively large increases in tractor cost is the different set

Fig. 8--Tractor costs, 1913-1950. SOURCE: Case studies--listed in Table 6, p. 96; Moving average--calculations listed in Appendix A; Index calculations listed in Appendix A.

of circumstances for these studies. The average tractor size for those studies was considerably greater than normal. This resulted in higher fuel consumption, interest, depreciation and lubrication costs. The tractors involved in these studies are simply more expensive to operate. To alleviate this problem and to lessen its impact, a moving average of tractor costs per year was calculated.[94] This is a moving average based on three consecutive time periods.[95] The moving average lessens the fluctuations and leaves an approximate costs of tractor operation for an average tractor for the years 1914 to 1939. This is represented by the dotted line on Figure 8. It shows a more stable, but still declining cost of tractor operations for that period of time.

A third estimation of tractor costs was employed for two purposes. The first reason was to estimate the trend of tractor costs after 1939, which was the date of the last case study used. The second reason was to check out the accuracy of the other estimations of tractor costs preceeding 1939. This estimation of tractor costs was calculated by the use of indexes for the major costs of tractor operation.[96] The base period was 1939. The base figures are derived from case study 20 in Table 6. The costs for that year include depreciation and interest of $114.00, repairs and maintenance of $18.00, fuel and lubrication of $75.00 and miscellaneous costs of $7.00. These figures are based upon 400 hours of tractor operation per year. The average size tractor used in this study is a 1.7 plow tractor. The average age of tractors used in this

study is 3.1 years. Tractor costs are estimated using these base figures from 1913 to 1950. The figures for depreciation and interest costs per year are calculated at a rate of 16.48% of the average price of a new two-plow tractor or a 10-20 horsepower tractor. Fuel and lubrication costs are based upon an index of gasoline prices. Repairs and maintenance costs are based upon the price of production goods paid by farmers. Miscellaneous costs are calculated on that same production index. These figures should give a close approximation of the costs involved in the operation of a two-plow or 10-20 horsepower tractor for the years 1913 to 1950. The total cost per year of these tractor costs is illustrated in Figure 8. These costs are shown with a solid line. It shows tractor costs decreasing from a high of $470.00 in 1913 to lows of $206.00 in 1931 and $205.00 in 1940. From 1940, the total costs increase quickly to $439.00 in 1950. These figures have fewer large fluctuations than with the figures from the case studies. This seems reasonable because the earlier figures were not adjusted on the basis of tractor size. These latest figures hold both hours of usage and size of tractor constant. In comparing these figures with the case studies where the average size tractor was approximately the same, this estimation of the cost of operating a small tractor compares very favorably. This last estimation of tractor costs is probably a good approximation of the costs involved in operating a two-plow or 10-20 horsepower tractor on the average farm during the period from 1913 to 1950.

Costs of Horses and Mules

The alternative to the use of tractor power was animal power. The calculation of the cost of using horses or mules for farming is less difficult than for tractors. While all horses are not homogeneous, they are much more similar to one another than are tractors. The estimation of the cost of using horses per year is calculated on the basis of an average of two case studies.[97] These studies separated the major costs of horse power into five categories. These are feed, labor for upkeep, interest and depreciation, harnesses and miscellaneous costs. These costs are shown in Table 7.

TABLE 7

COSTS OF USING A SINGLE HORSE PER YEAR

Year	Feed	Labor	Interest and Depreciation	Harness	Misc.	Total Cost
1921	39.75	7.42	16.94	4.53	.53	69.26
1917	95.39[a]	11.80	15.58[a]	3.72	1.54	128.03
1917 (1921 $'s)	62.75	13.06	13.86	3.05	1.26	93.98
Av. Cost (1921 $'s)	51.25	10.24	15.40	3.79	.94	81.62

ADAPTED FROM: N. H. Tolley and W. Humphries, pp. 1-59; W. F. Handsein, J. B. Andrews, and E. R. Rauchenstein, pp. 169-223.

[a]Estimated from data.

The costs for all the years are calculated on the basis of price indexes of the major costs using 1921 as the base year.[98] The price of feed was determined from an index of the value of crops. Labor was figured from an index of wage rates on farms. The cost of interest and depreciation was calculated at the rate of 17% of the average value per head of horses and mules. The interest and depreciation cost in 1921 was $15.40, which was equal to 16.8% of the average value of a horse or mule. The costs of harnesses and miscellaneous costs were based upon the price index of production goods paid by farmers. The total cost using horses or mules was a simple sum of these costs. The results of this estimation of horse and mule costs is presented in Figure 9. It is plainly evident that there are great fluctuations of the costs of horses and mules. The primary reason for sharp increases and decreases in the cost of horses and mules are the sharp increases and decreases in the cost of feed. Feed costs varied from $99.54 in 1921 to a low of $31.77 in 1932 and a maximum of $111.39 in 1947. Wage rates paid by farmers also accounted for a substantial change in the total costs of operating horses and mules. The cost of labor for horse upkeep varied from $15.82 in 1920 to a minimum of $5.78 in 1933 and to a peak of $29.01 in 1948. These two items were most responsible for the trend in the total cost. The total cost varied from $140.92 in 1920 to a low of $44.09 in the midst of the depression and to a high of $161.06 in 1947. This estimation of the costs involved with using horses (mules)

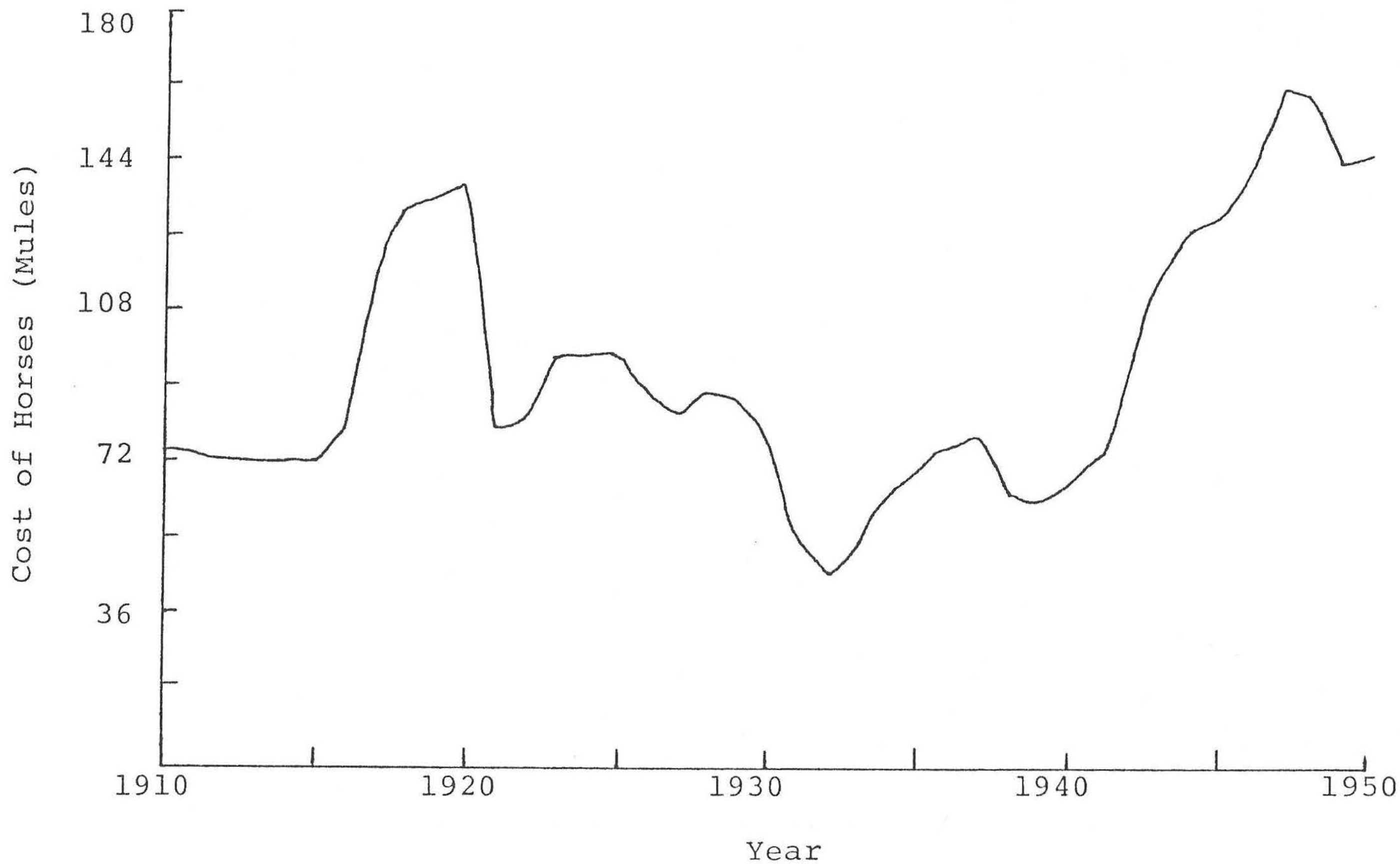

Fig. 9--Cost of horses (mules) 1910-1950. SOURCE: Calculations listed in Appendix A.

on the farm shows that, in general, the costs were increasing in the period from 1910 to 1920, decreasing from 1920 to 1932 and again increasing from 1932 to 1950.

Tractor Costs Versus Animal Costs--A Comparison

The comparison between the costs of operating a tractor versus the costs of using horses or mules is important to determine whether there was economic incentive to adopt the tractor. It would also give an indication if the rate of adoption of the tractor was delayed for non-economic reasons. It is hypothesized that the farmer did adopt the tractor for economic reasons. The rate of diffusion of the tractor should correspond closely to increased economic advantages of the tractor. If it is the case that the rate of diffusion of the tractor is dependent upon the economic advantage of the tractor, then this analysis should give an indication of the changing supply or demand conditions most responsible for affecting the diffusion rate of the tractor. If it is the case that the rate of diffusion of the tractor is unrelated to the economic advantages of the tractor, then other non-economic reasons will need to be examined.

This analysis attempts to find the difference between the total costs of using the tractor compared to the total costs of using the horse (mule) on the farm during 1910 to 1950. The previous two sections have already determined most of the costs necessary to make this comparison. The costs of operating

the tractor from 1913 to 1950 has been estimated. The cost figures that will be employed in this section are the figures from indexes of the major costs of tractor operation. The base period for this study is cost figures obtained in a case study in 1939. The costs of operating the horse (mule) also has previously been estimated in an earlier section. These costs are based upon indexes of the major costs involved in the operation of the horse. These figures are for one horse per year. They are based upon the average of two case studies and the base period is 1921. These figures cannot be compared directly in the form they were previously estimated. The figures must be made comparable. The first step is to make the two-plow tractor comparable to the appropriate number of horses. This size of tractor is generally compared to a four horse team.

A problem immediately arises because the tractor in 1910 is not the same as a tractor in 1950. Many improvements were made in the tractor during this period. This is a supply condition that undoubtedly had great impact. An adjustment must be included in the analysis to take into account the increases in efficiency of the tractor (the unadjusted data will also be presented). The adjustment is made by the use of a tractor efficiency coefficient. It is assumed in this paper that the tractor increased in efficiency 2.5 times from 1910 to 1950. There are reasons for this assumption. Some of the efficiency comes from newer tractors performing

performing tasks more rapidly than the old tractors. Probably most of the increased efficiency comes from the newer tractors performing tasks that the older tractors could not perform at all. Early tractors were basically used for soil preparation, while the later tractors were used for nearly all of the functions necessary for the farm. The increased efficiency was obtained through both improvements in the tractor itself and through improvements in implements. This increased efficiency is calculated on the basis of yearly increases during this period. This is the same as saying that the tractor could perform as well as 1.6 horses in 1910, but could perform as well as four horses in 1950.

There is also one other factor that must be taken into account before a direct comparison can be made between the costs of using the horses and the costs of using the tractor. This is the fact that using horses is more labor intensive than using tractors. It takes less time to perform nearly all farm tasks with the tractor compared to the horse. In the earlier section on the usefulness of the tractor versus the horse, it was shown in 1929 that performing farm tasks with a small tractor takes considerably less time than with a team of four horses. It is also true that the costs of operating a horse in the earlier section is based upon 800 hours of used, compared to only 400 hours of use for the tractor. These were based upon a rough average of the case studies that were examined. In the light of this information, it does not seem

inappropriate to estimate that using horses consumes 400 additional hours (50 days) of labor time per year based upon a four horse team.

The final step is to calculate the adjusted costs of operating the horses and subtract that from the adjusted costs of operating the tractor. The result is the cost difference between using the horses (mules) versus the tractor for the years 1913 to 1950.

The results of the adjusted data show that the tractor generally had higher costs from 1913 to 1926. The tractor had lower costs from 1934 to 1950. The years from 1927 to 1933 show tractor and horse costs nearly equal. The results are in Figure 10. Figure 10 illustrates the cost differential between horses and tractors as well as comparing this cost differential to the number of tractors per farm. If economic factors are the primary factors causing the farmer to adopt the technique of farming with the tractor, then there should be a definite correlation between the adjusted cost differential and the number of tractors per farm. The results indicate that there is a correlation between the cost differential and the number of tractors on the farm. During the period from 1915 to 1920, the cost of the tractor decreased rapidly compared to the cost of horses. This decreasing cost was associated with an increasing number of tractors on the farm,

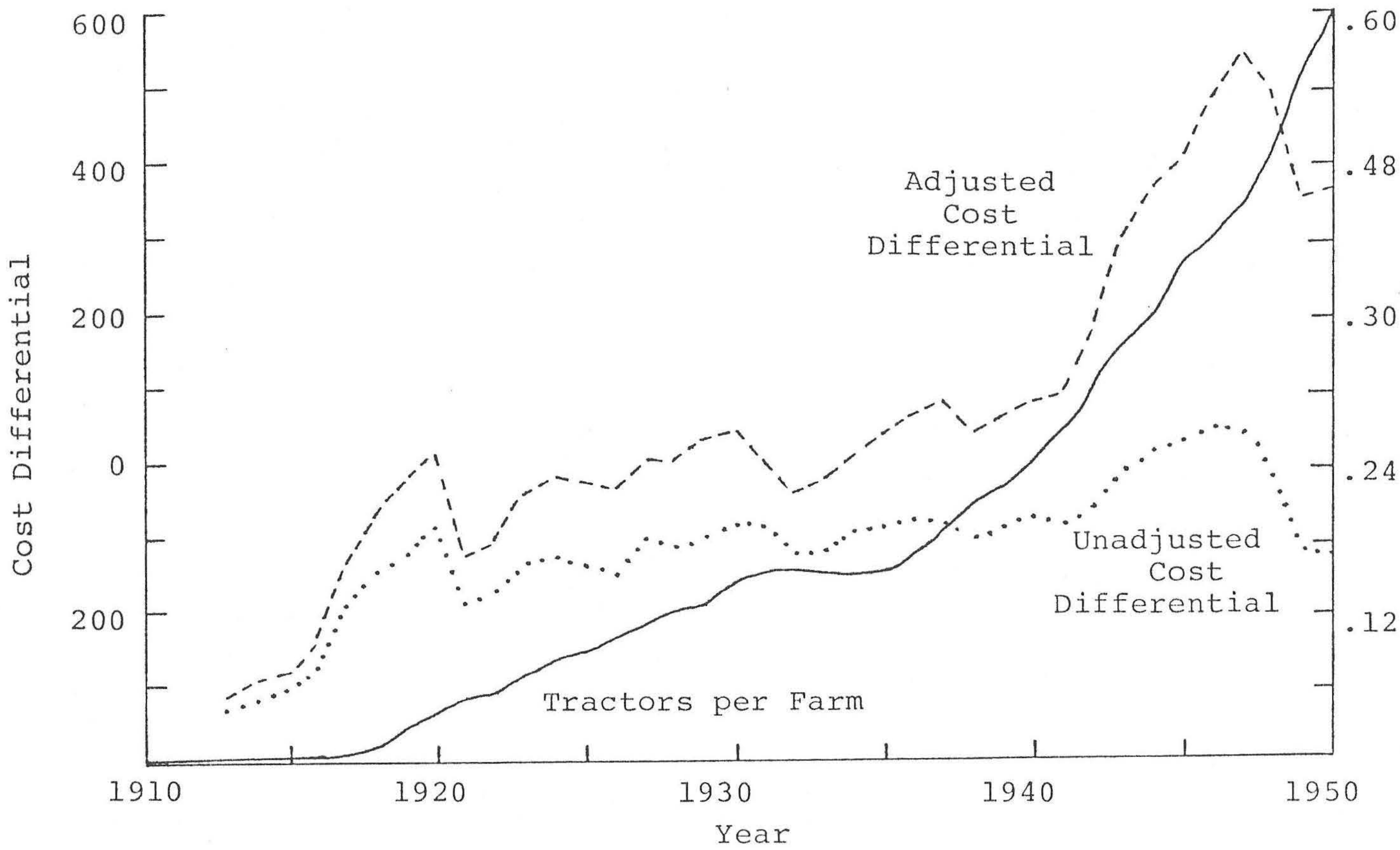

Fig. 10--Adjusted cost differential, unadjusted cost differential compared to tractors per farm. SOURCE: Adjusted and unadjusted cost differentials--calculations listed in Appendix A. ADAPTED FROM: Tractors per farm--U.S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States, p. 278, 285.

but with a lag of approximately one to two years. The number of tractors began to increase during the years from 1917 to 1921. The costs of operating the tractor increased compared to the operation of a team of horses during 1920 to 1921, which was followed by a period where tractor usage remained relatively constant. The costs of operating the tractor decreased reletive to the operation of the horse in the periods from 1915 to 1920, 1921 to 1924, 1926 to 1930, 1932 to 1937, and 1938 to 1947. All five of these periods in tractor costs relative to horse costs are accompanied by an increase in the number of tractors per farm with a year or two lag. During the periods when tractor costs were increasing in relationship to horse costs, the number of tractors remained relatively constant. This relationship held true throughout the whole period. The cost differential between the uses of horses and the use of tractors apparently affected the rate of diffusion of the tractor. As the costs of the use of the tractor decrease conpared to the costs of the use of the horse, the number of tractors per farm increases. When the costs of the tractor increase in relationship to the costs of the horse, the number of tractors per far remain relatively constant. The number of tractors per farm would not decrease unless this cost differential is long lasting because the tractor is a large capital investment and is usable for many years. During the Great Depression, the costs of operating

the tractor did increase relative to the operation of the horse for two years and did not obtain the same cost differential for a period of five years. This occured during the years 1930 to 1935. This resulted in a slight decrease of the number of tractor per farm from 1932 to 1934.

The unadjusted cost differential illustrates the importance of the increased efficiency of the tractor. This unadjusted cost differential assumes that the two-plow tractor replaced only 1.6 horses during the entire time period. If the assumed 2.5 efficiency is correct, then this increase in efficiency had a major impact on the cost differential.

The relationship would be much clearer if the adjusted cost differential is compared to the number of new tractors sold each year. This would show more closely how the farmer reacted to changes in the relative costs of the tractor and the horse. Figure 11 shows the close correlation between the adjusted cost differential and tractors sold.[99] During the years from 1913 to 1941, there is an extremely close relationship between the cost differential and the number of tractors sold. The years that the cost differential was most favorable to tractors were followed by more tractors being purchased by farmers. The relationship for the years 1942 to 1946 do not follow the same pattern as earlier years. As the costs of operating a tractor became more economical than the

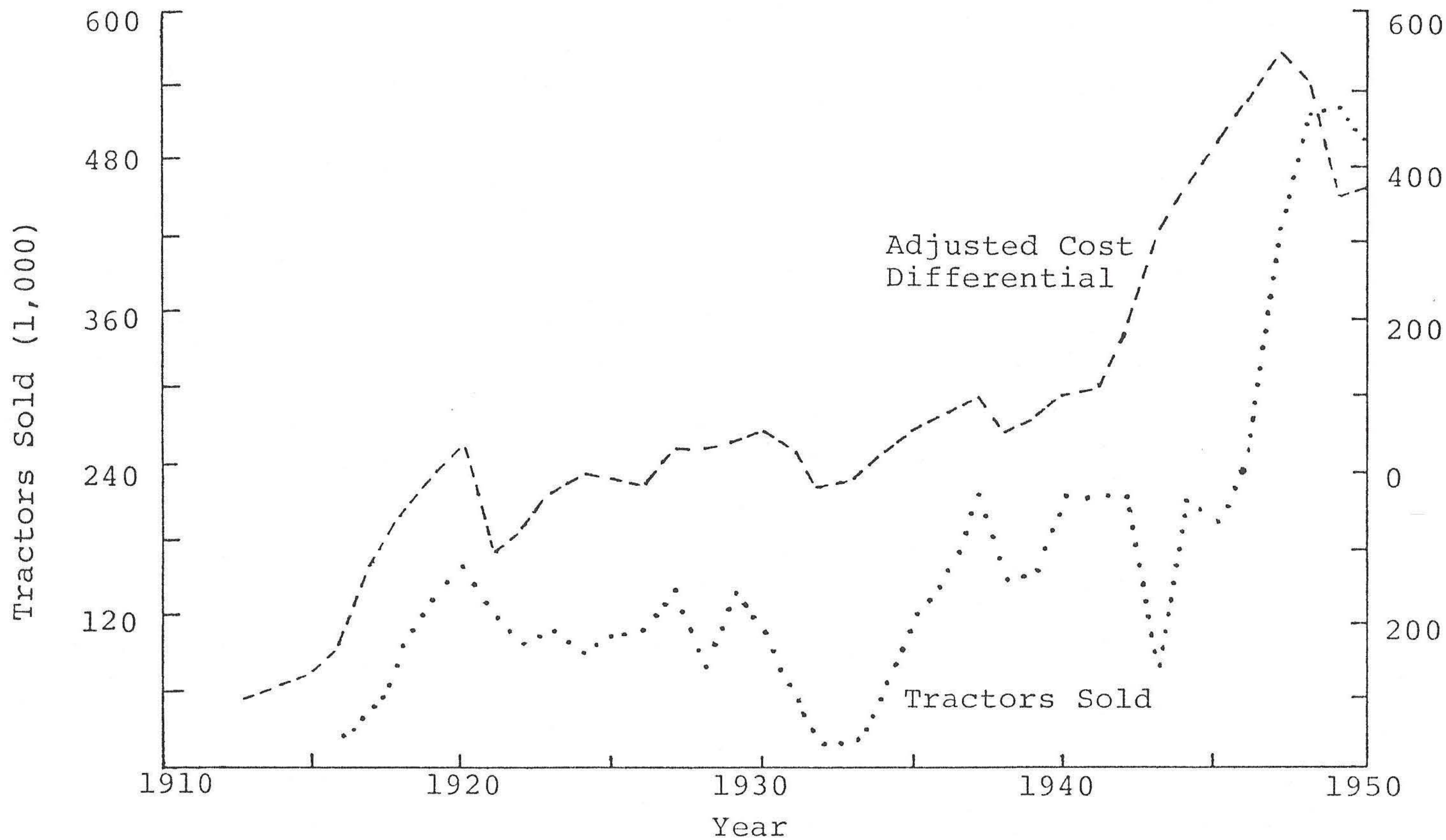

Fig. 11--Adjusted cost differential compared to number of tractors sold. SOURCE: Adjusted cost differential--calculations list in Appendix A. ADAPTED FROM: Number of tractors sold, 1916-1928--U.S.D.A., Agricultural Statistics 1940, p. 560; Number of tractors sold, 1929-1950--U.S.D.A., Agricultural Statistics 1951, p. 537.

operation of a team of horses, the number of tractors both manufactured and sold sharply dropped. This is evident from the years 1941 to 1943 and from 1944 and 1945. The reason for this relationship is the economic turmoil caused by World War II. Tractor production became of secondary importance in the war effort of this country. Following the war, between 1946 and 1949, tractor production increased tremendously and the number of tractors sold increased sharply.

It is now possible to assert that the diffusion rate of the tractor followed rather closely the adjusted cost differential between the operation of the tractor and a team of horses. During those years, the cost of tractor operations decreased relative to the costs of horse use, the number of tractors on the farm and the number of tractors sold increased. During those years that operating a horse decreased in costs relative to operating a tractor, the number of tractors on the farm stayed relatively constant and the number of tractors sold decreased. The farmer adopted the tractor at the same rate that there were economic incentives to do so. The cost differential between tractors and horses shows that the horse was a competitive technique until the early 1940's. It is not the case where the farmer failed to adopt the tractor because of ignorance of incompatibility. The use of a team of horses was a viable alternative during most of the period from 1910 to 1950. Tractor use began to increase when the

average costs of operating a tractor were well above the average costs of operating a team of horses. The reason is that one farm can have a different set of environmental conditions than another. The land, crops and climate changes from one farm to another. One farm can be ideal for the adoption of the tractor while another farm would not be able to use the tractor successfully for many years to come. The point is that the tractor was used economically during the early period of tractor development. This may have led to the idea that the rate of the diffusion of the tractor was delayed even though it was more economical to operate. This conclusion is false. Though the tractor was successfully used on some farms during its early years of development, it was not until the mid-thirties that the tractor could claim to be the more efficient technique on the average farm. The tractor was more efficient than the horse during 1920 and 1927 to 1931, but even as late as 1932 the horse was more economical to operate on the average farm. The conclusion is that the diffusion rate of the tractor is closely correlated with the farmers' economic incentives to adopt the tractor.

An important question is whether supply and demand conditions most affected the diffusion rate of the tractor. Several changing conditions were responsible for the diffusion rate of the tractor. The most important single factor is probably the improvement of the tractor during the period from 1910 to 1950. The historical development of the tractor tells much of the story why the tractor diffused as slowly as it did. The

efficiency of the tractor gradually increased during this period. It was not the increased drawbar power that caused most of this increased efficiency, but the increased versatility of the tractor. The early tractor could only do part of the work required around the farm. Horses had to be kept to perform the other tasks. As the tractor became more and more versatile, the need to keep horses diminished until they were no longer needed at all.

The factor which is probably second in importance in explaining adoption of the tractor is the change in labor costs during this period. Farming with the horses is more labor intensive than farming with the tractor. The index of farm wage rates increased from 96 in 1910 to 425 in 1950 (1910-1914=100). With a team of four horses in 1910, the labor required to operate that team of horses compared to the tractor was worth $67.50 in 1910. These combined for a total of $97.70 in 1910, which was 26% of the total costs of operating horses. There was a dramatic change by 1950. In that year, upkeep alone for four horses cost $111.60. The additional labor time for using this technique cost $225.00. The total labor cost in 1950 rose to $336.60. This was 42% of the total cost. More incredible than the increase from 1910 to 1950 is the fact that in 1933, the total cost of labor was only $80.62, which was 32% of the total. The increase from 1933 to 1950 of farm wage rates ended the competitiveness of the horses as a technique of farming.

A third factor affected the rate of diffusion of the tractor in two separate ways. This factor is the changing price of crops received by the farmer. As the price of crops increased, the costs of feeding horses a percentage of that crop increased simultaneously. This increased the total costs of farming with horses and resulted in an increase of tractors on the farm. The second effect of the increase of the price of crops was to increase the income of the farmer, which enabled the farmer to purchase the tractor. The tractor was a large capital investment for the farmer. The price of crops from 1910 to 1950 fluctuated greatly. The index of crop prices received by farmers was 105 in 1910 and generally increased to an early peak of 235 in 1920 (1910-1914=100). From that period, the price of crops decreased until the end of the Great Depression. The index of the price of crops reached its minimum of 57 during 1932. These low prices kept many horses on the farm. It was inexpensive to feed the horses during this period of time and at the same time the farmer did not have the money necessary to purchase new machinery. It was during the Depression that this factor influenced the diffusion of the tractor to the greatest extent. Following the Depression, the price of crops received by the farmer increased to a peak of 263 in 1947. This sudden increase in both the cost of feed and the income of the farmer speeded the rate of the diffusion of the tractor.

A fourth factor important in the rate of diffusion of the tractor was the initial cost of the tractor. In 1913,

the average two-plow tractor cost $1,162.00 and it decreased rapidly from that price to $628.00 in 1923. This definitely led to the increasing number of tractors purchased during those early years. During the years from 1923 to 1946, the tractor had a minimum cost of $602.00 in 1932 and had a maximum cost of only $767.00 in 1937. Only from 1946 to 1950 did the initial cost of the tractor begin to increase substantially. The unchanging cost of the tractor probably increased the diffusion rate of the tractor during the 1920's and 1940's but slowed the rate down during the Depression years.

The final factor that had a major impact upon the diffusion rate of the tractor is the price of gasoline and other fuel for the tractor. The price of gasoline declined from a maximum index value of 343 in 1913 to a low of 96 in 1940 (1939=100). It was during these years that the decreasing price of gasoline lowered the costs of operation of the tractor. While many other costs were higher, the price of gasoline was three times less expensive in 1940 than in 1913.

Anthropological and Sociological Factors

The analysis to this point in the paper has dealt primarily with economic factors in trying to establish the reasons for the diffusion of the tractor. While these economic factors explained much of the variance in the rate of diffusion,

additional insight into the adoption of the tractor is furnished by anthropological and sociological factors.

Sociological factors regarding the diffusion of the tractor are valuable to examine. Most of the literature on the diffusion process in Socioloty describes the diffusion process in steps. In the early part of this paper, these steps were classified into the stages of awareness, interest, evaluation, trial and adoption. The case of the tractor can be examined similarly. The farmer needed to proceed through these steps before the adoption of the tractor. For the farmer to participate in each of these stages was a relatively simple process after the early development of the tractor. The tractor was a highly visible product on the farm. There were also magazines, salesmen, community meetings, and extension agents discussing the tractor and its role on the American farm. It was next to impossible for the farmer not to be aware of the tractor. It also was easy for the farmer to begin to evaluate the tractor. The trial stage was accomplished by viewing the results of the tractor on those farms owning a tractor or watching tractor demonstrations. A farmer could not actually purchase a tractor for the trial purpose because of the high cost, but could obtain a good estimation of the worth of the tractor. There is no indication that delays occurred in adopting the tractor in any of these stages.

There are other sociological factors that may have affected the adoption of the tractor. The sociological variables

such as age, education or race are possibilities. These factors could determine the willingness of particular farmers to adopt new products or ideas. Well educated and young farmers theoretically would be more willing to adopt new products than the older farmer with little education. There seems to be some evidence to indicate this. In a study completed in 1950, in Louisiana, farmers who did not mechanize their farms were asked a series of questions about why they had not.[100] It is interesting that over thirty percent indicated that they were too old to mechanize their farms.[101] This is one example of the possible significance of sociological variables. There is evidence to indicate that sociological variables are of some significance in determining the adoption of the tractor, but because of the high visibility and popularity of the tractor, these sociological factors seem to have been generally minimal.

The anthropological literature concerning the diffusion process stresses the importance of the utility and compatibility of the new product or technique. Each culture has its own customs and values that are important in making a decision about the adoption of a new product. It is because of the culture of the United States that economic factors assume the importance they do. Economic factors are regarded as possessing great utility in the United States. The tractor became more economical to operate and thus created a greater utility to the farmer to adopt that technique. If economic factors were not the primary concern (with respect to the criteria for evaluating the tractor) of the farmer, then the adoption of

the tractor would not necessarily have occurred. It is similarly true of the compatibility of a new product or technique. The new product must be compatible with the culture of the people. The tractor was quite compatible with the culture of the farmers of the United States. The farmer was willing to substitute the use of the tractor for a team of horses. The tractor decreased the amount of hard and exhausting work the farmer must perform. It was easier for the farmer to perform the necesary tasks on the farm with the tractor than the horse. Considering the tractor after it became more efficient, one article discussing the adoption of the tractor states: "Almost anyone can appreciate the fact that it riding is easier on the individual than walking, and that handling a steering wheel is easier than maneuvering plow handles. Many farmers admit quite readily that this fact had much to do with their decision to mechanize."[102] Decreasing the workload of the farmer was compatible with the social system of the farmer of the United States. It may or may not have been compatible to farmers in other areas of the world. The concept of work is deeply ingrained in each peoples' culture.

The anthropological factors were probably the most important of all. These factors defined a social system and/or a belief system which, to use economic terminology, permitted "utility" to be derived from greater technical efficiency. In a system in which technical efficiency is not compatible with other beliefs, the tractor might not have been invented, much less adopted by virtually all farmers. The examination

of these anthropological factors, even as cursory an examination as this, puts the diffusion of the tractor into perspective.

Chapter 3--Notes

1 Wayne D. Rasmussen, ed., Readings in the History of American Agriculture (Urbania: University of Illinois Press, 1960), p. 159.

2 Reynold M. Wik, Steam Power on the Farm (Philadelphia: University of Pennsylvania Press, 1953), p. 200.

3 E. J. Baker, Jr., "A Quarter Century of Tractor Development," Agricultural Engineering 12 (June 1931): 206.

4 Roy B. Gray and E. M. Dieffenbach, "Fifty Years of Tractor Development in the U.S.A.," Agricultural Engineering 38 (June 1957): 390.

5 Wik, P. 206.

6 U. S. Department of Commerce, Bureau of Census, Historical Statistics of the United States: Colonial Times to 1957 (Washington, D.C.: U. S. Government Printing Office, 1960), p. 285.

7 Additional information concerning the number of tractors and horses on farms can be found in Appendix A.

8 U. S. Department of Agriculture, Agricultural Statistics 1957 (Washington, D.C.: U. S. Government Printing Office, 1958), p. 440.

9 It should be noted that tractors per farm and horses/mules per farm are downward biased when considering the average farm using these types of power. A substantial number of farms used neither source of power. These places are designated as farms but actually did not real farming themselves although they may have contracted their farming to others.

10 Robert Higgs, "Tractors or Horses? Some Basic Economies in the Pacific Northwest and Elsewhere," Agricultural History 49 (January 1975): 281.

11 Ibid., p. 281. Higgs also notes that one may wish to consider differences in maintenance costs or rates of depreciation. These will also be examined in the paper.

12 Gray and Dieffenbach, p. 388.

13 E. M. Dieffenbach and Roy B. Gray, "The Development of the Tractor," in Power to Produce, Yearbook of Agriculture 1960, U. S. Department of Agriculture (Washington, D.C.: U. S. Government Printing Office, 1960), p. 28.

14 Ibid., p. 29.

Chapter 3--Notes

15 Wik, p. 201.

16 Ibid.

17 Dieffenbach and Gray, p. 30.

18 Wik, p. 202.

19 Ibid.

20 "First Description of the Froelich Tractor," in Rasmussen, p. 160; originally appeared as "Another Gasoline Engine," Farm Implement News, 13 (December 8, 1892): 24-25.

21 Ibid., pp. 160-61.

22 Wik, p. 203.

23 Ibid.

24 Rasmussen, p. 159.

25 Wik, p. 203.

26 Ibid., p. 204.

27 Ibid.

28 Dieffenbach and Gray, pp. 31-32.

29 Ibid., p. 32.

30 Wik, p. 204.

31 Ibid.

32 Dieffenbach and Gray, p. 32.

33 Ibid.

34 Wik,p 205.

35 Baker, p. 206.

36 Ibid.

37 Gray and Dieffenbach, p. 392.

38 Baker, p. 206.

39 Wik, p. 205.

Chapter 3--Notes

40 Ibid., p. 393.

41 Gray and Dieffenbach, p. 392.

42 Ibid., p. 393.

43 Ibid., p. 392.

44 Ibid.

45 Ibid.

46 Dieffenbach and Gray, p. 32.

47 Ibid.

48 Gray and Dieffenbach, p. 393.

49 Ibid., p. 394.

50 Baker, p. 207.

51 Williams, p. 43.

52 Ibid., p. 44.

53 Gray and Dieffenbach, p. 394.

54 Ibid.

55 Ibid., p. 395.

56 Williams, p. 47.

57 Ibid.

58 Gray and Dieffenbach, p. 395.

59 Ibid.

60 Ibid.

61 Ibid.

62 Ibid., pp. 395-96.

63 Ibid., p. 396.

64 Ibid.

65 Ibid.

Chapter 3--Notes

66 Dieffenbach and Gray, p. 37.

67 Dieffenbach and Gray, p. 397.

68 Dieffenbach and Gray, p. 37.

69 Dieffenbach and Gray, p. 396.

70 David L. Lewis, _The Public Image of Henry Ford: An American Folk Hero and His Company_ (Detroit: Wayne State University Press, 1976), p. 180.

71 Ibid., p. 181.

72 Ibid.

73 Dieffenbach and Gray, p. 392.

74 Wik, p. 205.

75 Williams, p. 43.

76 U. S. Department of Commerce, Bureau of the Census, _1959 Agriculture Census_, vol. 1, _1959 Agricultural Census: Counties_, pts. 1-48 (Washington, D. C.: U. S. Government Printing Office, 1961) I:3.

77 Ibid.

78 Data from years 1920-1945, U. S. Department of Agriculture, Bureau of Agricultural Economics, _Farm Labor_ (Washington, D. C.: U. S. Government Printing Office, 1946), January 11, 1946, pp. 11-15; Data from year 1950, U. S. Department of Agriculture, Bureau of Agricultural Economics, _Farm Labor_ (Washington, D. C.: U. S. Government Printing Office, 1951), January 12, 1951, p. 12.

79 Tractors per farm calculated from number of tractors divided by the number of farms; number of tractors from, U. S. Department of Commerce, Bureau of the Census, _1959 Agriculture Census_, vol. 1, p. 7; number of farms from, U. S. Department of Commerce, Bureau of the Census, _1959 Agriculture Census_, vol. 1, p. 3; number of tractors not available for 1935, the number of tractors for year 1930 was used for that year.

80 Additional information of the computer analysis used is described in Appendix B.

81 U. S. Department of Commerce, Bureau of the Census, _1950 Census of Agriculture_, vol. 2, _General Report_ (Washington, D. C.: U. S. Government Printing Office, 1952) II:788-89.

Chapter 3--Notes

82
U. S. Department of Commerce, Bureau of the Census, vol. 2, pp. 1122-23; Farms included in this analysis are only commercial farms. Commercial farms include all farms, except abnormal farms, with a value of sales of farm products amounting to $1,200 or more. Commercial farms also include farms with a value of farm products sole of $250.00 to $1,199 provided the operator worked less than 100 days off the farm and that the operator and his family received less non-farm income than the total value of all farm products sold;

Class	Value of Farm Products Sold
I	$25,000 or more
II	$10,000 - $24,999
III	$5,000 - $9,999
IV	$2,500 - $4,999
V	$1,200 - $2,499
VI	$250.00 - $1,199

83
U. S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States: Colonial Times to 1957, p. 278. The value of the farm presented here is not completely comparable with the earlier definition. The value of the farm presented here includes the value of machinery and buildings.

84
Ibid., p. 280.

85
Ibid., pp. 278, 281. The size of the farm is calculated slightly different than before. Before it was calculated as the sum of acres of harvested crops plus the acres of cropland not harvested and not pastured per farm. It is presented here as only the acres of harvested crops.

86
Ibid., p. 285.

87
Additional information concerning value of the farm, farm wage rates and size of farm is shown in Appendix A.

88
Additional information on gasoline price index is shown in Appendix A.

89
Additional information on crop price index is shown in Appendix A.

90
U. S. Departmet of Agriculture, Interbureau Committee and the Bureau of Agricultural Economics, Technology on the Farm (Washington, D.C.: U. S. Government Printing Office, August 1940), p. 9.

Chapter 3--Notes

91 John A. Hopkins, Jr., Horses, Tractors and Farm Equipment, Iowa Agr. Exp. Sta. Bulletin 264, Ames, Iowa, 1929, pp. 393-398.

92 W. F. Handscin, J. B. Andrews and E. Rauchenstein, The Horse and the Tractor, Illinois Agr. Exp. Sta. Bulletin 231, Urbania, Illinois, 1921, p. 203.

93 John A. Hopkins, Jr., p. 387.

94 This three year moving average was found by taking three consecutive case studies and finding the average cost of tractor operation for that time period. For example, the cost of operating a tractor in 1922 was found by averaging the preceeding case study (or case studies), the case study (or case studies) for the year 1922 and the following case study (or case studies).

95 Additional information concerning the calculation of the moving average is found in Appendix A.

96 Additional information on index figures and individual costs of tractor usage is further illustrated in Appendix A.

97 N. H. Tolley and W. R. Humpheries, pp. 1-59; and W. F. Handscin, J. B. Andrews and E. R. Rauchenstein, pp. 169-223.

98 Additional information on individual costs of using horses is shown in Appendix A.

99 Additional information on the number of tractors sold is shown in Appendix A.

100 Alvin L. Bertrand, Agricultural Mechanization and Social Change in Rural Louisiana, Louisiana Agr. Exp. Sta. Bulletin 458, Baton Rouge, Louisiana, 1951, p. 15.

101 Ibid., p. 21.

102 Ibid.

CHAPTER 4

A GENERAL DISCUSSION OF THE TECHNIQUE OF FARMING WITH A TRACTOR

The reasons for farming with a tractor has been examined in the preceeding section. It was determined that farming with a tractor was slowly adopted primarily because of economic incentives. The diffusion rate of the tractor was consistent with the economic incentives to adopt the tractor. The farmer is an example of economic man. The farmer sought to increase his income by the incorporation of new techniques of farming. In this instance, the new technique was the tractor. But the tractor was not the only new technique introduced on the farm. There are many others during this same time period. Rural electrification, combines, cornpickers, hybrid corn, milking machines, fertilizers, scientific breeding and many other types of techniques were beginning to be used on the farm. Perhaps we can generalize and say that each of these other techniques were also adopted by the farmer because of economic incentives. The period from 1910 to 1950 can certainly be called a technological revolution in agriculture. The technological changes were caused by economic considerations. The farmer either stayed competitive or found it difficult to make a living. Large productivity increases were accomplished through improved techniques of farming.

These new technologies as well as many others were accepted into the society. Some of these technologies were found to have few harmful effects to the society and others were found to be very harmful to the society. These new technologies were developed and adopted for economic reasons and far too few people questioned other aspects of the techniques.

Up to this point, it has been determined that the farmer adopted the tractor generally when it was economic to do so. That fact, in itself, is interesting and worthwhile, but the object of this paper is to discuss the diffusion of the tractor in somewhat broader terms. A more explicit discussion of the tractor in terms other than solely economic will benefit the analysis. The tractor is a technique to provide power on the farm. The technique is neither entirely composed of mechanical parts or human components. It is a combination of both mechanical and human components. The tractor does not operate by iteself. The farmer must continuously interact with the machine for it to function correctly. A machine was defined earlier as consisting of parts, each specialized in function, that will perform work under human control. Not only is the tractor operated under human control, but it needs constant interaction between the machine and the farmer. The relationship between the farmer and the tractor calls for special attention. The question that can be asked is whether the tractor is a tool used by the farmer or whether the farmer has become just another specialized extension of the machine. The tractor can economically perform the task of providing power on the farm, but what has the

tractor done to the relationship between the farmer and his land? It is the nature of the tractor that is important here; the design of the tractor and its capabilities have already been thoroughly discussed. The farmer provided care and shelter for the horse. The farmer steered the horse, stopped the horse and speeded up the horse. The farmer did the same with the tractor. There are great similarities with farming with the tractor and farming with the horse. Farming with the horse called for more knowledge of medical supplies and harnesses. Farming with the tractor called for more knowledge of mechanics. The tractor could be operated at a greater speed and perform tasks the horse was unable to perform. The tractor was easier and more comfortable to ride on than the equipment pulled by the horse and did not require as much preparation each morning. These are some of the basic differences between the tractor and the horse. But the difference of the farmer driving the tractor compared to the farmer driving a team of horses was not revolutionary. Both were hard work. It was still hot and dusty on a tractor or on equipment pulled by a team of horses in the midst of summer. The tractor did not eliminate the work of the farmer. There were more similarities between the actual farming with the tractor compared to a team of horses than there were differences.

There are other ways that the nature of the tractor affected life on the farm. One such way is the fact that

farmers and especially their children interacted with the tractor differently than with a horse. There were many chores associated with horses. They had to be brushed and fed. Their stalls had to be cleaned regularly. There were few chores that were related to the tractor except for the older children who learned to drive and repair the tractor. These children began to get accustomed to machines. The boys learned how the tractor operated and how to repair machines. The mechanical arts were becoming part of the farm environment. Backgrounds in mechanics and engineering became valuable to the farmer. While many other sections of the economy had already been thoroughly industrialized, the agricultural section seemed to lag behind. It was during the period from 1910 to 1950, that the farm began to become highly industrialized. Throughout centuries, man farmed land with a strong back, a few horses or mules and a minimum of equipment. The tractor, along with other new techniques adopted, created an entirely different environment for the farming of land. Farming became more scientific. The farmer needed to know the chemical composition of the soil as well as the chemical compositions of fertilizers. The farmer needed to understand the mechanics of the tractor, the corn-picker, the combine and many other machines.

The nature of the tractor itself is important, but also of importance is the result of this new technique of farming. While the actual usage of the tractor was similar to a team of horses, the results that occurred when the tractor replaced

the horse changed many aspects of farm life. The tractor was both faster and more efficient than a team of horses. The primary result of this fact was that it took less labor and less time to farm the same amount of land. The farmer had several options. He could farm the same amount of land but reduce the family or hired labor. Another option would be to increase the amount of land that was farmed and keep the same amount of family and hired labor. During this period of time, the size of farms did increase their size. It has already been shown that the average acres of harvested crops per farm increased from 51 in 1910 to 63 in 1949. Considering the fact that not all these farms were commercial farms, the size of the farm did increase somewhat more than these figures would indicate. But the fact is still that the size of the average farm did not increase a great amount. The great concentration of farms did not occur during this time period. The immediate option that many farmers seem to take was the reduction of labor on the farm. Table 8 outlines the reduction of labor that occurred during 1910 to 1950.[1] The reduction of labor corresponds with the great increase of tractors during the late thirties and forties. The decrease in farm workers is also related to other new techniques adopted by the farmer during the same time period. It can be seen in Table 8 that both family workers and hired workers decreased during this period.

TABLE 8

THE NUMBER OF FAMILY WORKERS, HIRED WORKERS, AND TOTAL WORKERS ON FARMS

Year	Family Workers (1,000)	Hired Workers (1,000)	Total Workers (1,000)
1910	10,124	3,381	13,555
1915	10,140	3,452	13,592
1920	10.041	3,391	13,432
1925	9,715	3,321	13,036
1930	9,307	3,190	12,497
1935	9,855	2,878	12,733
1940	8,300	2,679	10,979
1945	7,881	2,119	10,000
1950	7,597	2,329	9,926

ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States, p. 280.

With the adoption of the tractor, especially the tractor of the forties, less labor was needed to plant, grow and harvest the crops. Hired workers could not find work on the farm and had to find other types of work. Other work was generally located in the city. The workers most affected by the adoption of the tractor seemed to be the workers on the southern farm. If the tractor itself did not displace the workers, new equipment pulled by the tractor did, especially in the harvesting

of crops. Skilled or semi-skilled farm laborers were transposed into unskilled city laborers. As the agricultural section decreased the number of workers on the farm, not only did the workers leave, but the communities surrounding farm areas lost population.

There are still other important factors. The tractor increased leisure time of the farmer, if the farmer did not increase the size of his land. To many farmers this was a relief. Farmers for centuries had worked long hours on the farm. The tractor eased the workload of the farmer. He could spend more time with his family and spend more time with community activities. The farmer became more self-sufficient in the sense that he could do most of the work himself. The farmer did not have to rely on hired workers as much. Many times during harvest season the farmer may have difficulties in finding workers at the right time. The tractor lessened this problem.

Another obvious result of the tractor was the reduction of the number of horses on the farm. It was shown earlier that the increase of tractors was negatively correlated with the number of horses per farm. The horse had been a part of life on the farm for centuries and the tractor was replacing the need for it. A machine was replacing a living creature as the power source for farming. The horse was replaced by the tractor and the interaction between the farm family and the tractor was different than with the horse. Another factor

is that the blacksmith's services were needed less. Mechanics replaced blacksmiths. People who specialized in supplying harnesses to the farmer were replaced by people specializing in selling machine parts to the farmer. These are some of the factors involved in fewer horses on the farm.

Some of the effects of the adoption of the tractor has been discussed in the preceeding section. What is evident from this brief outline is the fact that the tractor did affect many aspects of farm life besides those of an economic nature. Some of the aspects are good and others not. The fact is that the tractor was adopted by the majority of farmers only when it was economically feasible to do so. Other considerations were secondary in importance. This fact is of the utmost importance in discussing technological change. Only the immediate economic interest of the farmer was taken into account. Victor Ferkiss makes an interesting point on the decision-making process within our society:

> But the decision-making process of the market suffers from a fatal flaw: it is individualistic and antiholistic. Only the immediate economic interests of the buyer and seller are used as standards. Consequences for other parties - employees or suppliers, persons in other industries or nations, taxpayers and the unemployed - are all neglected. It is assumed an "invisible hand" will direct everything to the common good.[2]

This is the case of the adoption of the tractor. For those who believe that an "invisible hand" will direct everything to a common good, there would be no problems involved in this technological change. For those hesitant to accept the fact that the "invisible hand" will direct everything to a

common good, there are concerns. It is easy to adopt either viewpoint considering the adoption of the tractor. The tractor made the life of the farmer easier. Few farmers would want to go back to the days when horses were used to plow the fields. Labor was freed from agriculture to help build our industrial or service industry work force. The productivity of the farmer increased greatly. These can be considered as positive aspects of the adoption of the tractor. But at the same time, there are factors that are negative. Farm laborers went to the city and found no work. They became part of the city problem and many became unemployed. Many people consider life in a rural setting to be the best possible, but the rural population steadily decreased because of new techniques employed on the farm. Harvest season was traditionally a time of festivities and gatherings. Now the farmer could harvest his crops with a minimum of assistance. The farmer's allegiance was to his machines. The machine replaced man and animal. There are both positive and negative aspects of the diffusion of the tractor. There will be those who will praise the tractor and those who will curse it.

The crucial question that still needs an answer is whether the "invisible hand" will lead everything to a common good based upon only economic criteria. While that question will be debated for many years, the answer for the agriculture section of the economy during the years from 1910 to 1950 seems to be no. This seems especially true during the latter

years of this time period. There were traditions that were centuries old in farming. Many of these traditions were cherished to the farmer and the rural community as a whole. The adoption of one tractor by one farmer did not destroy many of the good institutions of the farm life, but it was the adoption of millions of tractors along with other machinery that spelled death to these institutions. The problem is that the farmer only based his decisions on one tractor. The individual farmer did not have the slightest idea of the eventual outcome of all the other farmers' decisions. This problem has occurred many times before in our society. The problem is very similar to the thesis of Garrett Hardin in his famous "Tragedy of the Commons."[3] Hardin used the example of herdsmen. In this example, each herdsman had to decide how many cattle he would graze on common pasture. He found that if each herdsman based his decision on only their own economic interests, the economic interests of all the herdsmen would suffer. Each herdsman would continue to graze more cattle even though the economic interest of the total group would suffer.[4] The same thing can happen and did happen to aspects of farm life. The farmer based his decision to adopt the tractor and other machinery on his individual economic interests. Some of the traditions in farming and the wholeness of the rural community are common goods. The decision of one farmer seemed minute, but the combined decisions of all farmers was powerful. The farmer did not believe it was

necessary to be concerned over these common aspects of farm life. It was the individual decisions of farmers that adopted new technology on the farm, but it was their combined decisions that destroyed some of the good aspects of farm life.

This is not to argue that the adoption of the tractor was a mistake. The tractor was one of the great inventions of the industrial age. The mistake is that the economic interest of the individual will lead to the best of all possible worlds. The fact is that, during the twentieth century, some good aspects of the society have been destroyed because of that assumption.

One element in the solution to this problem is a better understanding of technological change. Technological change affects many aspects of the society. Techniques adopted solely for economic reasons do not only affect economic aspects of the society, but these techniques affect many aspects of the society. Techniques adopted because of economic considerations should be examined beforehand for negative effects to the society. Only when the problems involved with technological change are understood, can solutions to those problems be found.

Chapter 4--Notes

1 U. S. Department of Commerce, Bureau of the Census, *Historical Statistics of the United States: Colonial Times to 1957*, p. 280.

2 Victor C. Ferkiss, pp. 212-13.

3 Garrett Hardin, "The Tragedy of the Commons," *Skeptic: The Forum for Contempory History*, special issue no. 2, *Scarcity*, pp. 13-18.

4 Ibid., p. 15.

LITERATURE CITED

Atchley, F. M. Tractor Costs in Michigan, 1937. Michigan Agricultural Experiment Station, The Quarterly Bulletin 23, East Lansing, 1940.

Baker, E. F., Jr. "A Quarter Century of Tractor Development." Agricultural Engineering 12 (June 1931): 206-07.

Barnett, H. G. Innovation: The Basis of Cultural Change. New York: McGraw-Hill Book Company, Inc., 1953.

Beal, George M. and Bolen, Joe M. How Farm People Accept New Ideas. North Central Regional Publication No. 1, Special Report No. 15, Iowa State College, Ames, Iowa, November, 1955.

______. The Diffusion Process. Iowa Agricultural Experiment Station Special Report 18, Ames, Iowa, 1957.

Berstrand, Alvin L. Agricultural Mechanization and Social Change in Rural Louisiana. Louisiana Agricultural Experiment Station Bulletin 458, Baton Rouge, Louisiana, 1951.

______. Rural Sociology: An Analysis of Contemporary Rural Life. New York: McGraw-Hill Book Company, Inc., 1958.

David, Paul A. "The Mechanization of Reaping in the Ante-Bellum Midwest." In The Economics of Technological Change. Edited by Nathan Rosenberg. Middlesex, England: Peter Smith, 1971; Penguin Books, Ltd., 1971.

Dieffenbach, E. M. and Gray, Roy B. "The Development of the Tractor." In Power to Produce. Yearbook of Agriculture 1960, U.S. Department of Agriculture. Washington, D.C.: U.S. Government Printing Office, 1960.

Ellul, Jacques. The Technological Society. Translated by John Wilkenson. With an introduction by Robert K. Merton. New York: Random House, 1964; Vintage Books, 1964.

Ferkis, Victor C. Technological Man: The Myth and the Reality. With a foreword by Elting E. Morrison. New York: New American Library, 1970; Mentor Books, 1970.

"First Description of the Froelich Tractor." In Readings in the History of American Agriculture. Edited by Wayne D. Rasmussen. Urbana: University of Illinois Press, 1960.

Fox, D. S. An Economic Study of the Gas Tractor in Pennsylvania. Pennsylvania Agricultural Experiment Station Bulletin 158, Centre County, 1919.

Gilbert, C. W. An Economic Study of Tractors on New York Farms. New York Agricultural Experiment Station Bulletin 506, Ithaca, 1929.

Gray, Roy B. and Dieffenbach, E. M. "Fifty Years of Tractor Development in the U.S.A." Agricultural Engineering 38 (June, 1957): 388-397.

Griliches, Zvi. "Hybrid Corn and the Economics of Innovation." In The Economics of Technological Change. Edited by Nathan Rosenberg. Middlesex, England: Peter Smith, 1971; Penguin Books, Ltd., 1971.

Hampson, C. M. and Christophersen, Paul. Tractor and Horse Power. South Dakota Agricultural Experiment Station Circular 6, Brookings, 1932.

Handscin, W. F., Andrews, J. B. and Rauchenstein, E. The Horse and the Tractor. Illinois Agricultural Experiment Station Bulletin 231, Urbana, Illinois, 1921.

Hardin, Garnett. "The Tragedy of the Commons." Skeptic: The Forum for Contemporary History, Special Issue No. 2 Scarcity.

Harley, C. K. "On the Persistence of Old Techniques: The Case of North American Wooden Shipbuilding." Journal of Economic History 33 (June 1973): 372-98.

Henning, Grayden R. and Trace, Keith. "Britain and the Motorship: A Case of the Delayed Adoption of New Technology?" Journal of Economic History 35 (June 1975): 353-85.

Higgs, Robert. "Tractors or Horses? Some Basic Economics in the Pacific Northwest and Elsewhere." Agricultural History 49 (January 1975): 281-82.

Hopkins, John A., Jr. Horses, Tractors and Farm Equipment. Iowa Agricultural Experiment Station Bulletin 264, Ames, Iowa, 1929.

Jerome, Harry. Mechanization in Industry. National Bureau of Economic Research Publication No. 27. New York: National Bureau of Economic Research, 1934.

Johnston, P. E. and Wills, J. E. The Study of the Cost of Horse and Tractor Power on Illinois Farms. Illinois Agricultural Experiment Station Bulletin 395, Urbana, 1933.

Lewis, David L. The Public Image of Henry Ford: An American Folk Hero and His Company. Detroit: Wayne State University Press, 1976.

Linton, Ralph. The Study of Man. New York: D. Appleton Century Company, 1936.

_____. Industrial Research and Technological Innovations: An Econometric Analysis. New York: W. W. Norton and Co., 1968.

Mansfield, Edwin. "Technical Change and the Rate of Imitation." In The Economics of Technological Change. Edited by Nathan Rosenberg. Middlesex, England: Peter Smith, 1971; Penguin Books, Ltd., 1971.

McLuhan, Marshall. Understanding Media: The Extensions of Man. New York: New American Library, Inc., 1964; Signet Books, 1964.

Mesthene, Emmanuel G. Technological Change: Its Impact on Man and Society. New York: New American Library, Inc., 1970; Mentor Books, 1970.

Morrison, F. L. The Tractor on Ohio Farms. Ohio Agricultural Experiment Station Bulletin 383, Columbus, 1925.

Mumford, Lewis. The Myth of the Machine. Vol. 1, Technique and Human Development. New York: Harcourt Brace Jananovich, Inc., 1966; A Harvest Book, 1967.

Myers, U. I. An Economic Study of Farm Tractors in New York. New York Agricultural Experiment Station 405, Ithaca, 1921.

Nelson, Richard R., Peck, Merton S. and Kalachek, Edward D. Technology, Economic Growth and Public Policy. Washington, D.C.: The Brookings Institution, 1967.

Nevins, Allen and Hill, Frank Ernest. Ford: Expansion and Challenge 1915-1933. New York: Charles Scribner's Sons, 1957.

Olmstead, Alan L. "The Mechanization of Reaping and Mowing in American Agriculture, 1833-1870." Journal of Economic History 35 (June 1975): 327-52.

Rasmussen, Wayne D., ed. Readings in the History of American Agriculture. Urbana: University of Illinois Press, 1960.

Rogers, Everett M. Diffusion of Innovations. New York: Free Press, 1957.

_____., ed. The Economics of Technological Change. Middlesex, England: Peter Smith, 1971; Penguin Books, Ltd., 1971.

Rosenberg, Nathan. Technology and American Economic Growth. New York: Harper and Row Publishers, 1972.

Schwentes, A. J. and Ponds, G. A. The Farm Tractor in Minnesota. Minnesota Agricultural Experiment Station Bulletin 280, St. Paul, 1931.

Selby, H. E. The Gas Tractor in Montana. Montana Agricultural Experiment Station Bulletin 151, Bozeman, 1922.

Trolley, N. H. and Humphries, W. Tractors and Horses in the Winter Wheat Belt, Oklahoma, Kansas, Nebraska. U.S. Department of Agriculture Bulletin 1202, Washington, D.C., 1924.

U. S. Department of Agriculture. Agricultural Statistics 1940, 1951, 1957. Washington, D.C.: U.S. Government Printing Office, 1940, 1951, 1957.

_____. Bureau of Agricultural Economics. Farm Labor. Washington, D.C.: U.S. Government Printing Office, 1946, 1951.

_____. Interbureau Committee and the Bureau of Agricultural Economics. Technology on the Farm. Washington, D.C.: U.S. Government Printing Office, 1940.

U.S. Department of Commerce. Bureau of the Census. Historical Statistics of the United States: Colonial Times to 1957. Washington, D.C.: U.S. Government Printing Office, 1960.

_____. Bureau of the Census. 1950 Census of Agriculture. Vol. 2, General Report. Washington, D.C.: U.S. Government Printing Office, 1952.

_____. Bureau of the Census. 1959 Agricultural Census. Vol. 1, 1959 Agricultural Census: Counties, pts. 1-48. Washington, D.C.: U.S. Government Printing Office, 1961.

_____. Bureau of the Census. Statistical Abstract of the United States 1939, 1941, 1944-45, 1948, 1950, 1951, 1952. Washington, D.C.: U.S. Government Printing Office, 1939, 1941, 1945, 1948, 1950, 1951, 1952.

_____. Bureau of Foreign and Domestic Commerce. Statistical Abstract of the United States 1923, 1928, 1930, 1933, 1937. Washington, D.C.: U.S. Government Printing Office, 1923, 1928, 1930, 1933, 1937.

Wik, Reynold K. Steam Power on the Farm. Philadelphia: University of Pennsylvania Press, 1953.

Wilkening, Eugene A. "The Process of Acceptance of Technological Innovations in Rural Society." In Rural Sociology: An Analysis of Contemporary Rural Life. Edited by Alvin L. Bertrand. New York: McGraw-Hill Book Company, Inc., 1958.

Wright, K. S. 1934 Tractor Costs in Michigan. Michigan Agricultural Experiment Station, The Quarterly Bulletin 18, East Lansing, 1935.

Yerkes, Arnold P. and Church, L. M. The Gas Tractor in Eastern Farming. U.S. Department of Agriculture Farmers' Bulletin 1004, Washington, D.C., 1918.

_____. Tractor Experience in Illinois: A Study of the Farm Tractor Under Corn-belt Conditions. U.S. Department of Agriculture Farmers' Bulletin 963, Washington, D.C., 1918.

Yerkes, Arnold P. and Moury, H. H. Farm Experience with the Tractor. U.S. Department of Agriculture Bulletin 174, Washington, D.C., 1915.

APPENDIX A

SUPPLEMENTARY TABLES

TABLE 9

NUMBER OF TRACTORS, HORSES AND MULES

ON FARMS, 1910 TO 1950

Year	Tractors (1,000)	Horses and Mules (1,000)	Farms (1,000)	Tractors per Farm	Horses and Mules per Farm
1910	1	23,321	6,406	.00016	3.64
1911	4	24,847	6,425	.00062	3.87
1912	8	25,277	6,430	.0012	3.93
1913	14	25,691	6,437	.0022	3.99
1914	17	26,178	6,447	.0026	4.06
1915	25	26,493	6,458	.0039	4.10
1916	37	26,534	6,463	.0057	4.11
1917	51	26,659	6,478	.0079	4.12
1918	85	26,723	6,488	.013	4.12
1919	158	26,490	6,506	.024	4.07
1920	246	25,199	6,518	.038	3.87
1921	343	25,137	6,511	.053	3.86
1922	372	24,588	6,500	.057	3.78
1923	428	24,018	6,492	.066	3.70
1924	496	23,285	6,480	.077	3.59
1925	549	22,082	6,471	.085	3.41
1926	621	21,986	6,462	.096	3.40
1927	693	21,192	6,458	.107	3.28
1928	782	20,448	6,470	.121	3.16
1929	827	19,744	6,512	.127	3.03
1930	920	18,738	6,546	.141	2.86
1931	997	18,468	6,608	.151	2.79
1932	1,022	17,812	6,687	.153	2.66
1933	1,019	17,337	6,741	.151	2.57
1934	1,016	16,997	6,776	.150	2.51
1935	1,048	16,676	6,814	.154	2.45
1936	1,125	16,226	6,739	.167	2.41
1937	1,230	15,802	6,636	.185	2.38
1938	1,370	15,245	6,527	.21	2.34
1939	1,445	14,792	6,441	.22	2.30
1940	1,545	13,932	6,350	.243	2.19

TABLE 9--Continued

Year	Tractors (1,000)	Horses and Mules (1,000)	Farms (1,000)	Tractors per Farm	Horses and Mules per Farm
1941	1,665	14,104	6,293	.265	2.24
1942	1,860	13,655	6,202	.300	2.20
1943	2,160	13,231	6,089	.337	2.17
1944	2,160	12,613	6,003	.360	2.10
1945	2,354	11,629	5,907	.395	1.95
1946	2,480	11,108	5,926	.418	1.87
1947	2,613	10,129	5,871	.445	1.73
1948	2,821	9,279	5,803	.486	1.60
1949	3,123	8,498	5,722	.546	1.49
1950	3,394	7,604	5,648	.601	1.35

ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States: Colonial Times to 1957 (Washington, D.C., U.S. Government Printing Office, 1960), pp. 278, 284-85, 289.

TABLE 10

FARM WAGE RATES, ACRES OF HARVESTED CROPS,

AND VALUE OF FARMS, 1910 TO 1950

Year	Farm Wage Rates per Day Without Board	Acres of Harvested Crops		Value of Farms	
		All Farms (1,000,000)	Per Farm	All Farms (1,000,000)	Per Farm
1910	1.35	325	51	34,793	5,431
1911	1.35	330	51	36,042	5,610
1912	1.40	329	51	37,298	5,801
1913	1.40	333	52	38,456	5,974
1914	1.35	334	52	39,579	6,139
1915	1.40	340	53	39,590	6,130
1916	1.50	340	53	42,265	6,540
1917	1.90	349	54	45,524	7,027
1918	2.45	364	56	49,980	7,703
1919	2.90	364	56	54,533	8,382
1920	3.30	360	55	66,310	10,173
1921	2.05	359	55	61,523	9,449
1922	2.00	355	55	54,050	8,315
1923	2.35	354	55	52,629	8,107
1924	2.40	355	55	50,487	7,791
1925	2.35	360	56	49,463	7,644
1926	2.40	359	56	49,000	7,583
1927	2.35	358	55	47,680	7,383
1928	2.30	361	56	47,532	7,347
1929	2.30	365	56	47,985	7,369
1930	2.15	309	56	47,873	7,313
1931	1.65	305	55	43,730	6,618
1932	1.20	371	55	37,180	5,560
1933	1.15	340	50	30,802	4,569
1934	1.25	304	45	32,201	4,752
1935	1.35	345	51	33,264	4,882
1936	1.45	323	48	34,260	5,084
1937	1.65	347	52	35,213	5,306
1938	1.55	349	53	35,170	5,388
1939	1.55	330	51	34,085	5,292
1940	1.60	339	53	33,636	5,297

TABLE 10--Continued

Year	Farm Wage Rates per Day Without Board	Acres of Harvested Crops		Value of Farms	
		All Farms (1,000,000)	Per Farm	All Farms (1,000,000)	Per Farm
1941	1.95	342	54	34,400	5,466
1942	2.55	346	56	37,547	6,054
1943	3.30	356	58	41,604	6,833
1944	3.95	361	60	48,200	8,029
1945	4.35	354	59	53,884	9,030
1946	4.80	351	59	61,046	10,301
1947	5.10	354	60	68,403	11,661
1948	5.40	356	61	73,664	13,694
1949	4.45	360	63	76,623	13,391
1950	4.50	354	61	75,256	13,324

ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States: Colonial Times to 1957 (Washington, D.C., U.S. Government Printing Office, 1960), pp. 278, 280, 281.

TABLE 11

INDEXES FOR FARM WAGE RATES, PRICES RECEIVED FROM CROPS, AND PRICES OF PRODUCTION GOODS PAID BY FARMS, 1910-1950

Year	Indexes of Prices Received and Paid by Farmers (1910-14=100)		
	Prices Received For Crops	Prices Paid For Production Goods	Farm Wage Rates
1910	105	97	96
1911	101	98	98
1912	100	102	101
1913	98	101	104
1914	96	102	101
1915	96	104	101
1916	120	115	112
1917	191	156	141
1918	220	180	177
1919	230	195	206
1920	235	195	241
1921	121	128	156
1922	136	127	154
1923	156	138	172
1924	159	140	182
1925	164	145	181
1926	139	141	183
1927	134	141	184
1928	142	148	184
1929	135	146	186
1930	115	135	177
1931	75	113	139
1932	57	99	104
1933	71	99	88
1934	98	114	99
1935	103	122	107
1936	108	122	114
1937	118	132	129
1938	80	122	130
1939	82	121	127
1940	90	123	129

TABLE 11--Continued

Year	Indexes of Prices Received and Paid by Farmers (1910-14=100)		
	Prices Received for Crops	Prices Paid for Production Goods	Farm Wage Rates
1941	108	130	151
1942	145	148	197
1943	187	164	262
1944	199	173	318
1945	202	176	359
1946	228	191	387
1947	263	224	419
1948	255	250	442
1949	224	238	430
1950	233	246	425

ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States: Colonial Times to 1957 (Washington, D.C., U.S. Government Printing Office, 1960), pp. 283.

TABLE 12

PRICES OF TRACTORS AND GASOLINE,

1913-1950

Year	Price of 2 - plow (10/20hp) Tractor (dollars)	Index of Tractor Prices (1939=100)	Price of Gasoline (dollars)	Index of Prices (1939=100)
1913	1,162.5	168	.168	343
1923	628.0	91	.134	273
1924	680.0	98	.122	249
1925	680.0	98	.133	271
1926	680.0	98	.128	261
1927	680.0	98	.092	188
1928	680.0	98	.099	202
1929	680.0	98	.091	186
1930	653.0	94	.073	149
1931	637.0	92	.050	102
1932	602.6	87	.057	116
1933	671.0	97	.051	104
1934	719.0	104	.052	106
1935	707.0	102	.052	106
1936	696.0	101	.056	114
1937	767.6	111	.058	118
1938	755.7	109	.054	110
1939	691.7	100	.049	100
1940	655.7	95	.047	96
1941	665.7	96	.066	135
1942	705.4	102	.071	145
1943	705.4	102	.074	151
1944	705.8	102	.077	157
1945	707.0	102	.075	153
1946	765.8	111	.071	145
1947	823.5[a]	119	.088[b]	180
1948	917.3[a]	133	.117[b]	239
1949	979.2[a]	142	.144[b]	294
1950	997.6[a]	144	.146[b]	298

ADAPTED FROM: U.S. Department of Commerce, Bureau of the Census, <u>Statistical Abstract of the U.S. 1923</u>, p. 314; <u>Statistical Abstract 1928</u>, p. 322-23; <u>Statistical Abstract 1930</u>,

TABLE 12--Continued

p. 345; Statistical Abstract 1933, pp. 283-84; Statistical Abstract 1937, pp. 303-04; Statistical Abstract 1939, p. 320; Statistical Abstract 1941, pp. 358-59; Statistical Abstract 1944-45, pp. 421-22; Statistical Abstract 1948, p. 300; Statistical Abstract 1950, p. 280; Statistical Abstract 1951, p. 280; Statistical Abstract 1952, p. 275.

[a]Tractor prices derived from index of agricultural machinery and equipment.

[b]Gasoline prices derived from index of petroleum products.

TABLE 13

MOVING AVERAGE OF TRACTOR COSTS,

1914-1939

Year	Total Cost	Average Cost For Each Year	Three Time Period Moving Average
1914	859	859	859
1917	275		
1917	363	367	556
1917	464		
1919	403	443	416
1919	483		
1920	439	439	476
1921	401		
1921	574	547	474
1921	665		
1922	399	437	480
1922	474		
1923	457	457	382
1926	201	251	322
1926	300		
1929	257	257	304
1930	347	405	288
1930	463		
1934	201	201	273
1939	214	214	214

ADAPTED FROM: Case studies listed in Table 6, p. 96.

TABLE 14

COSTS OF FARMING WITH THE TRACTOR,

1913-1950

Year	Deprecia-[a] tion & Interest (dollars)	Repairs &[b] Mainten- ance (dollars)	Lubrica-[c] tion Fuel (dollars)	Miscel-[d] laneous (dollars)	Total Cost (dollars)
1913	192	15	257	6	470
1923	104	21	205	8	338
1924	112	21	188	8	329
1925	112	22	203	9	346
1926	112	21	196	8	337
1927	112	21	141	8	282
1928	112	22	152	9	295
1929	112	22	140	9	283
1930	107	20	112	8	247
1931	105	17	77	7	206
1932	99	15	87	6	207
1933	111	15	78	6	210
1934	119	17	80	7	223
1935	116	18	80	7	221
1936	115	18	86	7	226
1937	127	20	89	8	244
1938	124	18	83	7	232
1939	114	18	75	7	214
1940	108	18	72	7	205
1941	109	19	101	7	236
1942	116	22	109	9	256
1943	116	24	113	9	262
1944	116	26	118	10	270
1945	116	26	115	10	267
1946	127	28	109	11	275
1947	136	33	135	13	317
1948	152	37	179	14	382
1949	162	35	221	14	432
1950	164	37	224	14	439

ADAPTED FROM: Base year 1939--Case study 20, Table 6, p. 96.

[a]Depreciation and interest derived from taking 16.48% of average price of tractor (based on year 1939).

[b]Repairs and maintenance derived from price of production goods index (based on year 1939).

[c]Lubrication and fuel derived from price of gasoline indes (based on year 1939).

[d]Miscellaneous derived from price of production goods index (based on year 1939).

TABLE 15

COSTS OF FARMING WITH THE HORSE

Year	Costs Paid by Farmers for One Horse per Year					
	a Feed	b Labor for Upkeep	c Interest and Depreciation	d Harness	e Misc	Total Cost
1910	44.47	6.30	18.68	2.87	.71	73.03
1911	42.78	6.43	19.34	2.90	.72	72.17
1912	42.36	6.63	18.40	3.02	.75	71.16
1913	41.51	6.83	19.22	2.99	.74	71.29
1914	40.67	6.63	19.02	3.02	.75	70.09
1915	40.67	6.63	17.84	3.08	.76	68.98
1916	50.83	7.35	17.66	3.41	.84	80.09
1917	80.90	9.26	17.99	4.62	1.15	113.92
1918	93.18	11.62	18.55	5.33	1.32	130.00
1919	97.42	13.52	17.83	5.77	1.43	135.97
1920	99.54	15.82	18.36	5.77	1.43	140.92
1921	51.25	10.24	15.40	3.79	.94	81.62
1922	57.60	10.11	12.80	3.76	.93	85.20
1923	66.07	11.29	12.67	4.09	1.01	95.13
1924	67.35	11.97	12.00	4.15	1.03	96.50
1925	69.46	11.85	11.76	4.29	1.06	98.45
1926	58.87	12.01	11.85	4.17	1.04	87.94
1927	56.76	12.08	11.34	4.17	1.04	85.39
1928	60.14	12.08	11.95	4.38	1.09	89.64
1929	57.18	12.21	12.44	4.32	1.07	87.22
1930	48.71	11.62	12.56	4.00	.99	77.88
1931	31.77	9.12	10.73	3.35	.83	55.80
1932	24.14	6.83	9.45	2.93	.73	44.08
1933	30.07	5.78	9.52	2.93	.73	49.03
1934	41.51	6.50	12.14	3.38	.84	64.37
1935	43.63	7.02	14.20	3.61	.90	69.36
1936	45.74	7.48	17.68	3.61	.90	75.41
1937	49.98	8.47	18.36	3.91	.97	81.69
1938	33.88	8.53	17.00	3.61	.90	63.92
1939	34.73	8.34	15.98	3.58	.89	63.52
1940	38.12	8.47	14.96	3.64	.90	66.09

TABLE 15--Continued

	Cost Paid by Farmers for One Horse per Year					
Year	Feed[a]	Labor[b] for Upkeep	Interest[c] and Depreciation	Harness[d]	Misc.[e]	Total Cost
1941	45.74	9.91	13.43	3.85	.95	73.88
1942	61.42	12.93	13.00	4.38	1.09	92.82
1943	79.20	17.20	15.79	4.86	1.20	118.25
1944	83.44	20.87	16.35	5.12	1.27	127.05
1945	85.56	23.57	14.21	5.21	1.29	129.84
1946	96.57	25.40	13.28	5.66	1.40	142.31
1947	111.39	27.50	13.89	6.63	1.65	161.06
1948	108.01	29.01	13.11	7.40	1.84	159.37
1949	94.88	29.23	12.00	7.05	1.75	143.91
1950	98.69	27.90	10.42	7.28	1.81	146.10

ADAPTED FROM: Base year 1921--Case studies, Table 7, p. 110.

[a]Feed derived from crop price index (based on year 1921).

[b]Labor derived from farm wage index (based on year 1921).

[c]Interest and depreciation derived from 17% average value of horse or mule (based on year 1921).

[d]Harness derived from price of production goods index (based on year 1921).

[e]Miscellaneous derived from price of production goods index (based on year 1921).

TABLE 16

COSTS OF OPERATING FOUR HORSES INCLUDING

ADDITIONAL LABOR TIME,

1910-1950

Year	Cost per Horse (dollars)	Cost of 4 Horses (dollars)	Cost of[a] Additional Labor Time (dollars)	Total Cost[b] of 4 Horses (dollars)
1910	73.03	292.12	67.50	359.62
1911	72.17	288.68	67.50	356.18
1912	71.16	284.64	70.00	354.64
1913	71.29	285.16	70.00	355.16
1914	70.09	280.36	67.50	347.86
1915	68.98	275.92	70.00	345.92
1916	80.09	320.36	75.00	395.36
1917	113.92	455.68	95.00	550.68
1918	130.00	520.00	122.50	642.50
1919	135.97	543.88	145.00	688.88
1920	140.92	563.68	165.00	728.68
1921	81.62	326.48	102.50	428.98
1922	85.20	340.80	100.00	440.80
1923	95.13	380.52	117.50	498.02
1924	96.50	386.00	120.00	506.00
1925	98.45	393.80	117.50	511.30
1926	87.94	351.76	120.00	471.76
1927	85.39	341.56	117.50	459.06
1928	89.64	358.56	115.00	473.56
1929	87.22	348.88	115.06	463.88
1930	77.88	311.52	107.50	419.02
1931	55.80	223.20	82.50	305.70
1932	44.08	176.32	60.00	236.32
1933	49.03	196.12	57.50	253.62
1934	64.37	257.48	62.50	319.98
1935	69.36	277.44	67.50	344.94
1936	75.41	301.64	72.50	374.14
1937	81.69	326.76	82.50	409.26
1938	63.92	255.68	77.50	333.18
1939	63.52	254.08	77.50	331.58

TABLE 16--Continued

Year	Cost per Horse (dollars)	Cost of 4 Horses (dollars)	Cost of[a] Additional Labor Time (dollars)	Total Cost[b] of 4 Horses (dollars)
1940	66.09	264.36	80.00	344.36
1941	73.88	295.92	97.50	393.02
1942	92.82	371.50	127.50	498.78
1943	118.25	473.00	165.00	638.00
1944	127.05	508.20	197.50	705.70
1945	129.84	519.36	217.50	736.86
1946	142.51	570.04	240.00	809.24
1947	161.06	644.24	255.00	899.24
1948	159.37	637.48	270.00	907.48
1949	143.91	575.64	222.50	798.14
1950	146.10	584.40	225.00	809.40

NOTE: Horse costs derived from index method.

[a]Additional labor time figured as an extra 400 hours per year for a 4-horse team.

[b]Total cost of 4 horses is found by adding cost of 4 horses and costs of additional labor time.

TABLE 17

COSTS OF OPERATING 1.6 HORSES AND

UNADJUSTED COST DIFFERENTIAL,

1910-1950

Year	Total Cost 1.6 Horses (dollars)	Cost of[a] Additional Labor Time for 1.6 Horses (dollars)	Cost of Tractor[b] Minus Cost of 1.6 Horses (dollars)
1910	116.85	27.00	-
1911	115.47	27.00	-
1912	113.86	28.00	-
1913	114.06	28.00	327.94
1914	112.14	27.00	317.86
1915	110.37	28.00	305.63
1916	128.14	30.00	271.86
1917	182.27	38.00	196.73
1918	208.00	49.00	147.00
1919	217.55	58.00	115.45
1920	225.47	66.00	86.53
1921	130.59	41.00	192.41
1922	136.32	40.00	174.68
1923	152.21	47.00	138.79
1924	154.40	48.00	126.60
1925	157.52	47.00	141.48
1926	140.70	48.00	148.30
1927	136.62	47.00	98.38
1928	143.42	46.00	105.58
1929	139.55	46.00	97.45
1930	124.61	43.00	79.39
1931	89.28	33.00	83.72
1932	70.53	24.00	112.47
1933	78.45	23.00	108.55
1934	102.99	25.00	95.01
1935	110.98	27.00	83.02
1936	120.66	29.00	76.34
1937	130.70	33.00	80.30
1938	102.27	31.00	98.73
1939	105.74	32.00	81.37

TABLE 17--Continued

Year	Total Cost 1.6 Horses (dollars)	Cost of[a] Additional Labor Time for 1.6 Horses (dollars)	Cost of Tractor[b] Minus Cost of 1.6 Horses (dollars)
1940	105.74	32.00	67.26
1941	118.21	39.00	81.79
1942	148.51	51.00	56.49
1943	189.20	66.00	6.80
1944	203.28	79.00	-12.28
1945	207.74	87.00	-27.74
1946	228.02	96.00	-49.02
1947	257.70	102.00	-42.70
1948	254.99	108.00	19.01
1949	230.26	89.00	112.74
1950	233.76	90.00	115.24

NOTE: Horse costs and tractor costs derived from index method.

[a]Additional labor time figured as an extra 160 hours per year for a 1.6-horse team.

[b]Cost of tractor minus cost of 1.6 horses is the unadjusted cost differential.

TABLE 18

COSTS OF OPERATING VARYING NUMBER OF HORSES

AND ADJUSTED COST DIFFERENTIAL,

1910-1950

Year	Horses [a] Displaced 2.5:1 efficiency ratio	Horses Left [b]	Cost of Horses Left (dollars)	Cost of [c] Additional Labor Time of Horses Left (dollars)	Total Cost of Tractor and Number of Horses Left (dollars)	Cost of [d] Tractor & Horses Left Minus Cost of 4 Horses (dollars)
1910	1.6	2.40	175.27	40.50	-	-
1911	1.66	2.34	168.88	39.49	-	-
1912	1.72	2.28	162.24	39.90	-	-
1913	1.78	2.22	158.26	38.85	667.11	311.95
1914	1.84	2.16	151.39	36.45	644.84	296.98
1915	1.90	2.10	144.86	36.75	625.61	279.69
1916	1.96	2.04	163.38	38.25	631.63	236.27
1917	2.02	1.98	225.56	47.03	689.59	158.91
1918	2.08	1.92	249.60	58.80	712.40	69.90
1919	2.14	1.86	252.90	67.43	711.33	22.45
1920	2.20	1.80	253.66	74.25	705.91	-22.77
1921	2.26	1.74	142.02	44.59	550.61	121.63
1922	2.32	1.68	143.14	42.00	536.14	95.34
1923	2.38	1.62	154.11	47.59	539.70	41.68
1924	2.44	1.56	150.54	46.80	526.34	20.34
1925	2.59	1.50	147.68	44.06	537.74	26.44
1926	2.56	1.44	126.63	43.20	506.83	35.07
1927	2.62	1.38	117.84	40.54	440.38	-18.68
1928	2.68	1.32	118.32	37.95	451.27	-22.29
1929	2.74	1.26	109.09	36.23	429.13	-34.75
1930	2.80	1.20	93.46	32.25	372.71	-46.31
1931	2.86	1.14	63.61	23.51	293.12	-12.58
1932	2.92	1.08	47.61	16.20	270.81	34.49
1933	2.98	1.02	50.01	14.66	274.67	21.05
1934	3.04	.96	61.80	15.00	299.80	-20.18
1935	3.10	.90	62.42	15.19	298.61	-46.33
1936	3.16	.84	63.34	15.23	304.57	-69.57
1937	3.22	.78	63.72	16.09	323.81	-85.45
1938	3.28	.72	46.02	13.95	291.97	-41.21
1939	3.34	.66	41.92	12.79	268.71	-62.87

TABLE 18--Continued

Year	Horses Dis-Placed 2.5:1 Effi-ciency Ratio[a]	Horses Left[b]	Cost of Horses Left (dollars)	Cost of Addi-tional Labor Time of Horses Left (dollars)[c]	Total Cost of Tractor and Num-ber of Horses Left (dollars)	Cost of Tractor & Horses Left Minus Cost of 4 Horses (dollars)[d]
1940	3.4	.60	39.65	12.00	256.65	- 87.71
1941	3.46	.54	39.90	13.16	292.06	-100.96
1942	3.52	.48	44.55	15.30	315.85	-182.93
1943	3.58	.42	49.67	17.33	329.00	-309.00
1944	3.64	.36	45.74	17.78	333.52	-372.18
1945	3.70	.30	38.95	16.31	322.26	-414.60
1046	3.76	.24	34.20	14.40	323.60	-485.64
1947	3.82	.18	28.99	11.48	357.47	-541.77
1948	3.88	.12	19.12	8.10	409.22	-498.26
1949	3.94	.06	8.63	3.34	443.97	-354.17
1950	4.0	0.00	0.00	0.00	439.97	-369.43

NOTE: Horse and tractor costs derived from index method.

[a]The number of horses displaced if the farmer purchased a 2-plow tractor.

[b]The number of horses the farmer would still have on the farm after the purchase of a 2-plow tractor.

[c]Additional labor time; figure as an extra 400 hours per year for a 4-horse team.

[d]Cost of tractor and horses left on the farm after the purchase of a tractor minus the cost of 4 horses is the adjusted cost differential.

TABLE 19

NUMBER OF TRACTORS MANUFACTURED

AND TRACTORS PURCHASED,

1910-1950

Year	Tractors Manufactured (1,000)	Tractors Purchased (1,000)	Year	Tractors Manufactured (1,000)	Tractors Purchased (1,000)
1910	4	-	1931	62	58
1911	7	-	1932	-	25
1912	12	-	1933	-	25
1913	7	-	1934	-	65
1914	15	-	1935	138	122
1915	21	-	1936	194	165
1916	30	28	1937	238	221
1917	63	50	1938	172	151
1918	133	96	1939	186	161
1919	165	136	1940	249	219
1920	203	163	1941	313	297
1921	68	-	1942	172	218
1922	95	96	1943	105	85
1923	127	111	1944	249	215
1924	112	92	1945	244	199
1925	158	114	1946	258	255
1926	170	117	1947	433	428
1927	185	147	1948	530	517
1928	152	87	1949	556	520
1929	196	137	1950	498	506
1930	176	116			

ADAPTED FROM: Tractors purchased 1915-1928--U.S. Department of Agriculture, Agricultural Statistics 1940, p. 560; Tractors purchased 1929-1950--U.S.D.A. Agricultural Statistics 1951, p. 537; Tractors manufactured (wheel type), 1910-1928--U.S.D.A. Agricultural Statistics 1940, p. 560; Tractors manufactured 1929-1950--U.S.D.A. Agricultural Statistics 1951, p. 538.

APPENDIX B

COMPUTER ANALYSIS

TECHNICAL INFORMATION ON COMPUTER ANALYSIS

Years 1920, 1925, 1930, 1935, 1940

Program Used: STATISTICAL ANALYSIS SYSTEM (SAS)

Procedure Card for Regression Coefficients: PROC REGR

Procedure Card for Correlation Coefficients: PROC CORR

Years 1945, 1950

Program Used: STATISTICAL ANALYSIS SYSTEM (SAS76)

Procedure Card for Regression Coefficients: PROC SYS REG S

Procedure Card for Correlation Coefficients: PROC CORR